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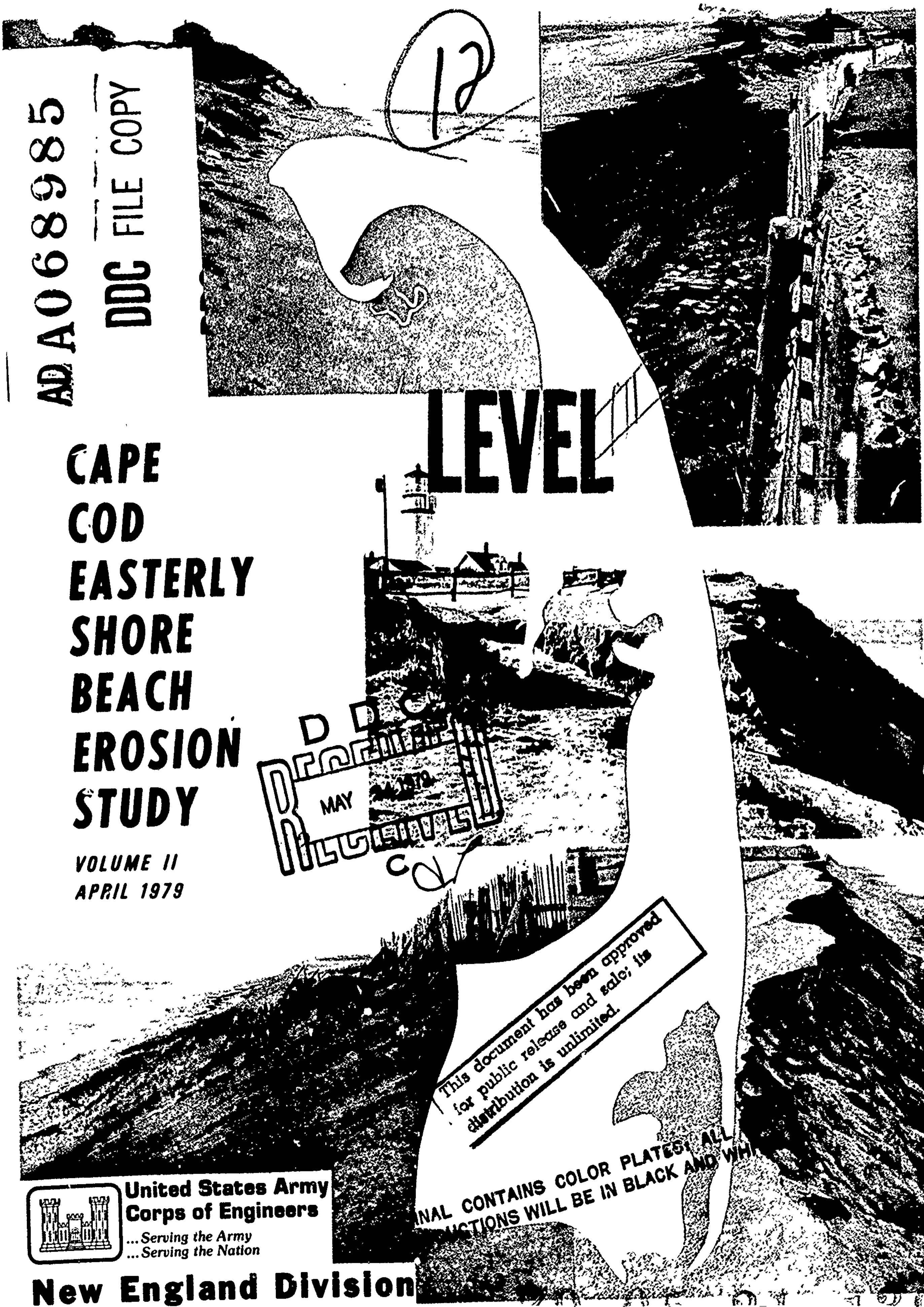
CAPE COD EASTERLY SHORE BEACH EROSION STUDY

VOLUME II

APRIL 1979



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The report is designed to encourage the National Park Service and locals to improve their beaches using non-structual methods. The report is divided into 3 volumes- Vol. I-main report, Vol. II Technical report, Vol. III Reconnaissance reports. Vol.I discussed the study area in general with recommendations and conclusions. Vol.II discussed in detail the erosion and accretion causing elements. Vol.III- individual town and National Park Service reconnaissance reports describing each area, discussing the problems and suggesting solutions.

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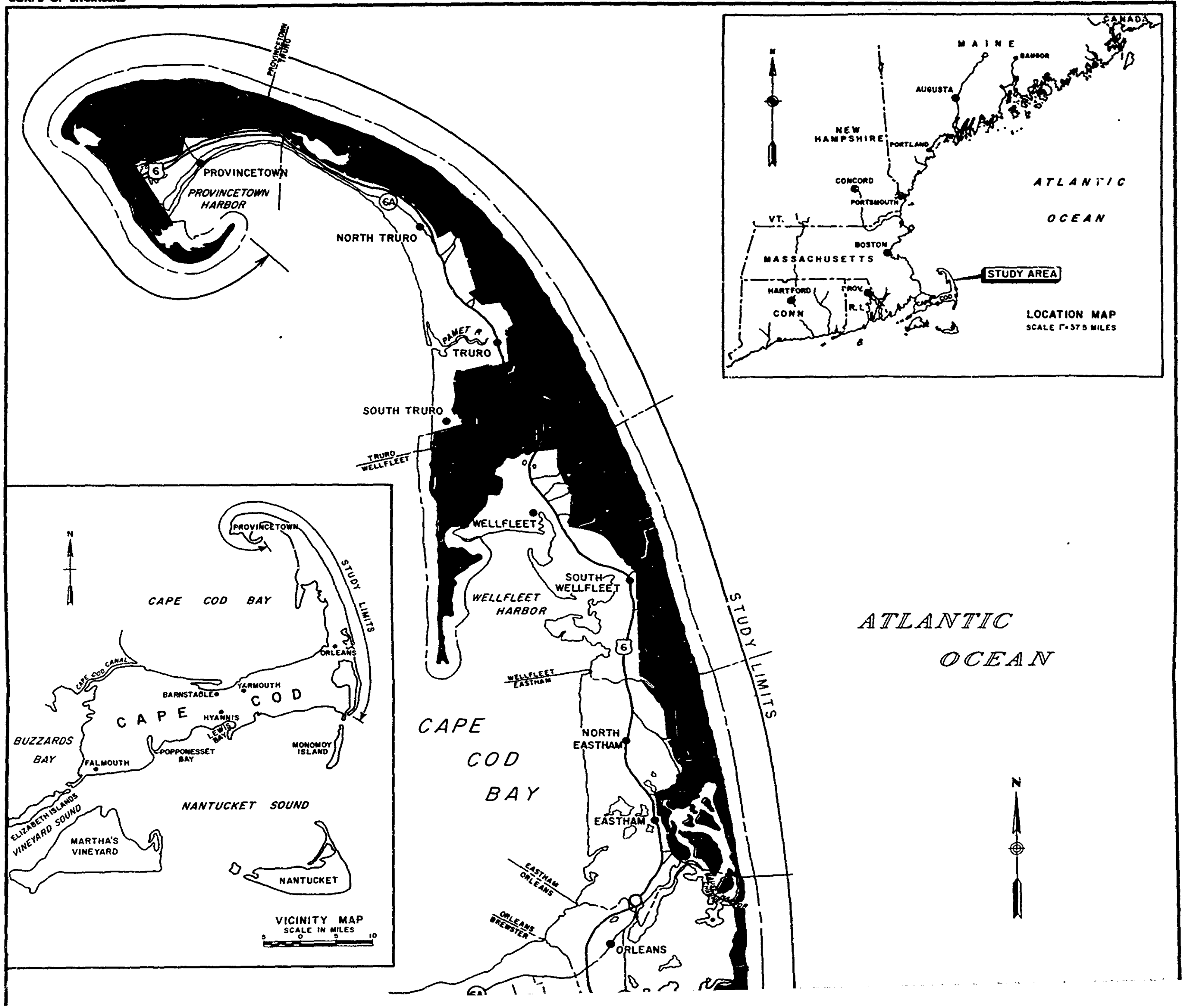
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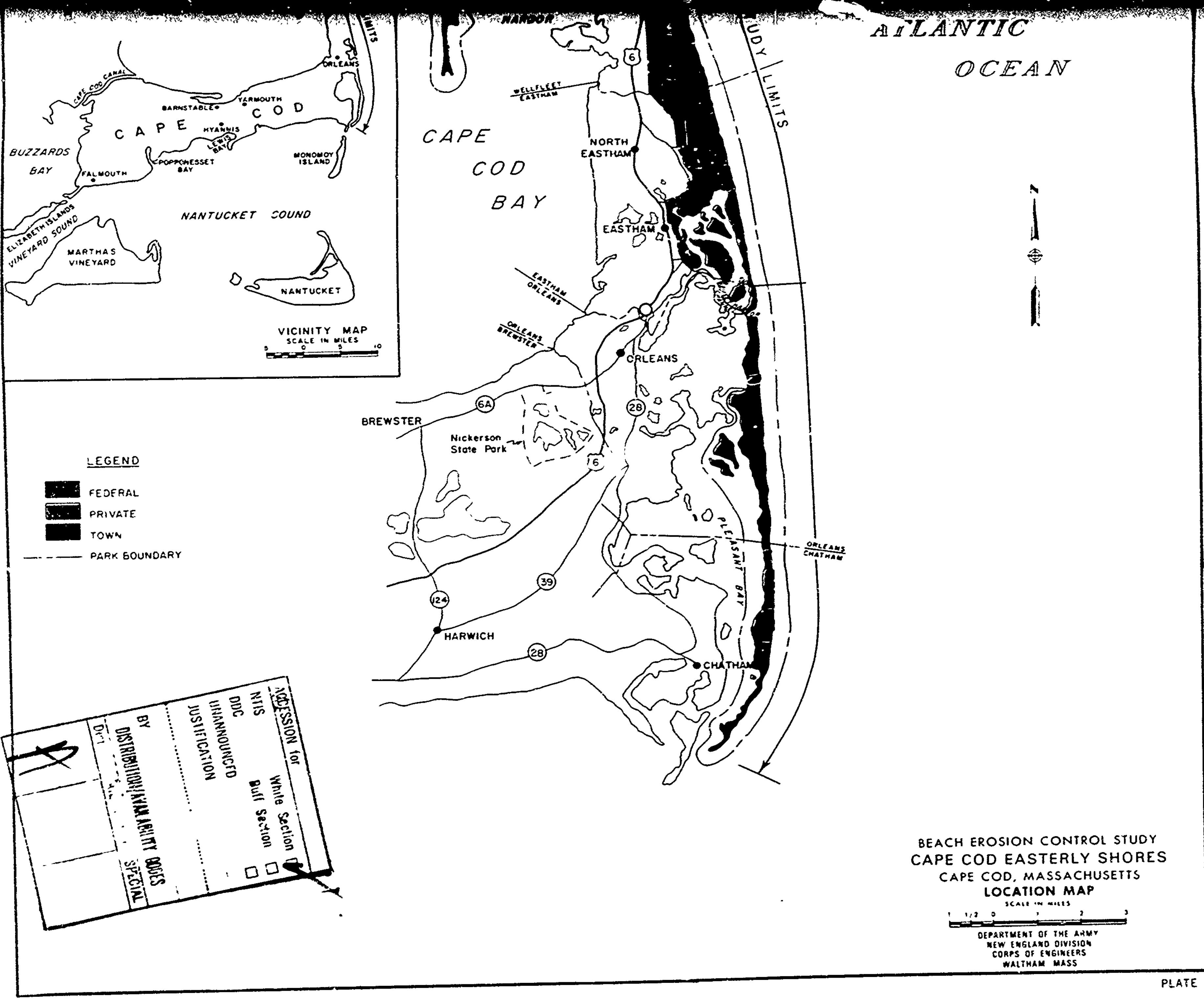
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NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM MASS

PLATE 1

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APPENDIX 1

SHORE PROCESSES

PREPARED BY

THE NEW ENGLAND DIVISION

CORPS OF ENGINEERS DEPARTMENT OF THE ARMY

CAPE COD EASTERLY SHORE
BEACH EROSION CONTROL STUDY

VOLUME II
APPENDICIES

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PREFACE

This volume consists of selected technical and historical data gathered from publications, documents and pamphlets related to shore processes and the Cape Cod area. It also contains a list of publications of work by other prominent authors who have published their work or have knowledge of this area. Alternative plans of improvement for arresting the erosion were considered along with a social and economic effect assessment to determine if an economical plan of improvement was justified and would qualify for federal assistance under the current requirements of the Corps' beach erosion control program. Based on the Corps' current beach erosion control authority criteria for federal participation in the cost of construction of shore protection, the improvements considered for the easterly shore were found to be adequate to retard the erosion but not economically justified for federal participation. Therefore, this volume is designed to provide the user with historic information, preliminary background on waves, hydrology, shoreline changes and other pertinent information that would be of assistance to engineers, geologists, scientists and other interested groups, organizations and individuals.

ACKNOWLEDGMENTS

This report was made under the direction of:

John P. Chandler, Colonel, Corps of Engineers, Division Engineer

John L. Ignazio, Chief, Planning Division

It was completed under the supervision of Mr. Oscar Arpin, former Chief, Coastal Development Branch; Mr. Donald Martin, Chief, Coastal Development Branch. Mr. Thomas C. Bruha, Project Manager, developed the report and Analysis & Technology, Inc., of North Stonington, Connecticut researched pertinent data, summarized and evaluated technical information and prepared the final report.

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GEOLOGY

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GEOLOGY

INTRODUCTION

When the Pilgrims reached Cape Cod in 1620, William Bradford was pleased at the sighting. He is reported to have said, "And the appearance of it much comforted us, especially seeing so goodly a land....." Most of us who have visited the Cape would agree with Bradford's words. The miles of beaches, surrounding ocean, high cliffs, gentle wooded lands, quiet ponds and lakes, secluded harbors, and magnificent vistas all speak to us of a special place. Thoreau's "bare and bended arm of Massachusetts" is one of nature's best creations, a gift that has been enjoyed by local residents and visitors ever since man first set foot upon it. Part of the beauty and fascination of the Cape is that it is constantly changing.

Geological evidence reveals that the Cape has been undergoing change not only in historical times, but during its entire existence. In order to understand these present and past landform changes and to acquire some basis for estimating the effects of future changes, we must investigate the origin of the Cape.

Cape Cod, which extends approximately 25 miles eastward and 30 miles northward into the Atlantic Ocean, is a very recent addition to the landmass of Massachusetts. The material comprising the visible Cape was deposited by glacial ice which spread over the area from the north, finally leaving the area about 12,000 years ago. The original deposits have since been shaped by tides, winds, waves, and currents into the topography that Cape Cod displays today. The outline of the Cape has changed significantly in the past several hundred years. Because the Cape is composed of unconsolidated sediments (primarily sand and gravel) that can be eroded easily, the rate of change has been extremely rapid. The rate of erosion and land sculpting is so high that, geologically speaking, Cape Cod and the associated islands are temporary features, with a life expectancy measured in thousands, not millions, of years.

This section explains the reasons for the rapid landscape change of Cape Cod through a discussion of its geological history. Special emphasis will be placed on the formation and continual change of the various features of the Cape and on the natural and cultural processes that affect these changes.

ORIGIN AND EXTENT OF GLACIATION

Cape Cod is composed of unconsolidated sedimentary material lying on crystalline bedrock. Bedrock is located at depths of between 400 feet (south of Nauset Inlet) and 900 feet (north of Truro) (Oldale, 1969). Thus, the bedrock surface has no influence on the current topography. Most of the sediments are of glacial origin but some workers (Zeigler et al, 1960; Oldale and Tuttle, 1964; Strahler, 1972; and Fisher, 1972) have reported possible discontinuous subsurface occurrences of earlier formed deposits lying between the glacial sediments and bedrock. The glacial sediments, deposited during the last ice age, form the material presently being eroded.

The ice age, or more properly, the ice ages, occurred during the Pleistocene epoch which began one to two million years ago and ended 10,000 years ago. There is evidence to suggest that the ice advanced four times over the northern part of this continent, with each advance being separated by a warmer interglacial period. The glacial deposits of Cape Cod belong to the last of the four advances that occurred during the Wisconsin stage of glaciation. Evidence from fossil marine shells suggests that this advance reached the Cape area about 20,000 years B.P. (before present) (Zeigler et al, 1964). The age of the glacial sediments is inferred from radio carbon dating to be approximately 14,000-15,000 B.P. (Oldale et al, 1968).

The glaciers, large masses of ice that formed from recrystallized snow and flowed under their own weight, began in Canada. Snowfall in Canada did not melt from year to year and gradually piled up to such a thickness that it eventually turned to ice. Slowly the ice masses grew until they could no longer support their own weight and began to flow laterally. More and more masses grew and flowed together, finally coalescing into gigantic ice sheets which spread outward.

The Wisconsin ice that affected Cape Cod spread from a center in Hudson Bay and Labrador approximately 80,000 years B.P. The ice sheet, over 10,000 feet thick in some places, extended as far south as New York City, Long Island, Martha's Vineyard, and Nantucket. Figure 1-A1 is a sketch map of North America showing the maximum extent of ice coverage during the Pleistocene.

GEOLOGICAL WORK OF GLACIERS

The leading edge of the ice sheet spread inexorably southward, at first parting and going around hills and then, as the ice became thicker, flowing

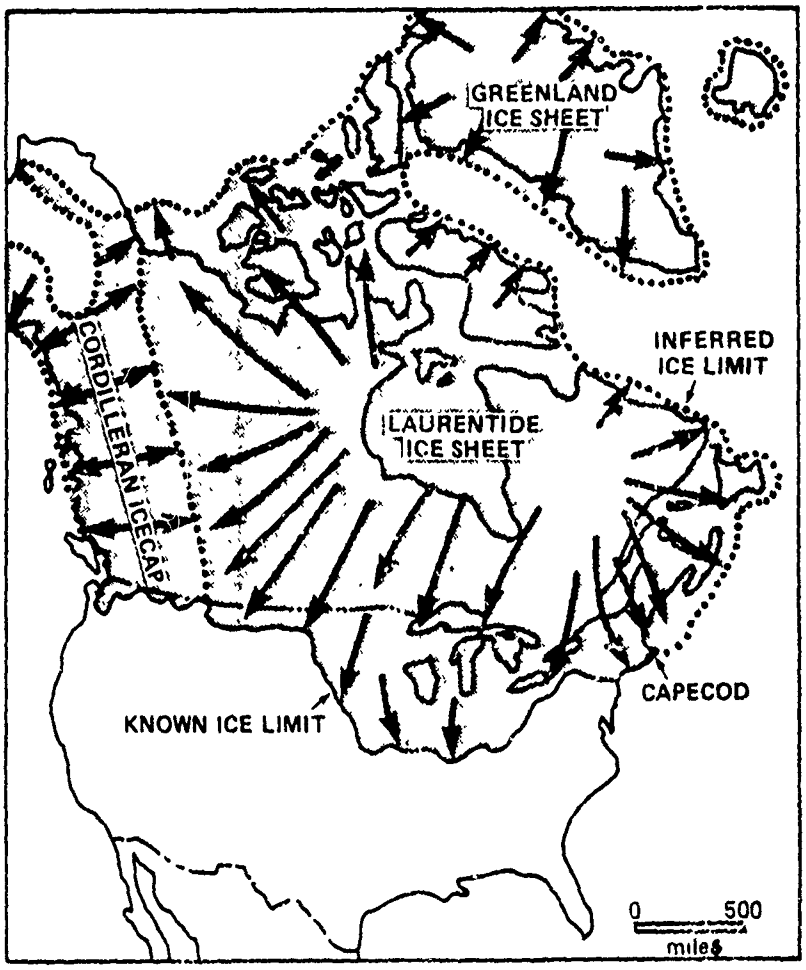

Figure 1-A1. Maximum extent of ice during Pleistocene (Strahler, 1966)

over the tops of even the highest mountains in Massachusetts. The moving ice, driven by the cool temperature and accumulating snow, acted as a very powerful agent of erosion as it moved over New England. Weathered rock material was picked up and ground down to sand, silt, and clay by the crushing and grinding effect of the glacier. Large chunks of rock were quarried from the bedrock surface. This accumulation of material increased the glacier's abrasive action on the surface beneath it. The erosion was pronounced because it involved land that had been weathered during the millions of years prior to the Pleistocene.

The ice sheet continued to advance, however, only as long as the rate of ice being supplied from the source exceeded the rate of melting at its southern extremities. Eventually a warming trend increased the rate of melting and caused the frontal margin of the ice sheet to reach a period of standstill and then retreat.

As the ice melted, the rocks and sediment it was carrying were left behind forming the glacial deposits of sand, gravel, and boulders that are seen today. Even when the margin of the ice sheet was stationary or in a state of retreat, the ice was still moving forward; that is, the ice continued to flow south regardless of whether the frontal margin of the ice advanced, retreated, or stood still.

Rock material carried by the ice was dumped or deposited both from the body of the ice, itself, and at the margins of the ice sheet. Most deposition occurred at the margin of the sheet, however. It is this depositional aspect of glaciation that is most significant when dealing with the origin and formation of Cape Cod. All the rocks and rock material eroded and transported south by the ice were deposited and left behind as the ice front retreated northward when the climate turned warmer again. In the area of the Cape and Islands, the climate was warm enough to cause continual melting from the edge of the ice. As the ice at the margin melted, the sedimentary debris incorporated in that ice was either dumped in place on the ground or spread out in front of the ice by the action of meltwater streams. Material deposited directly from the ice is termed <u>till</u> and is an unsorted, unstratified mixture of various sizes of particles ranging from clay to large cobbles. <u>Stratified drift</u> is the term applied to the more stratified sediments that have been sorted by size and deposited from meltwater streams. <u>Glacial drift</u> is the general term applied to both till and stratified drift. Drift of both types is abundant in the area of Cape Cod.

Glacial deposits are formed during all three stages of glacier movement, that is, when the margin of the ice sheet is advancing, standing still, or retreating. Most materials deposited during the advancing stage are subsequently removed or disturbed by later deposits and consequently seldom constitute a major part of the surficial geology of an area; Cape Cod is no exception. It is during the time of ice margin standstill that the greatest thickness of glacial deposits usually accumulates. The moving ice brings a continuous flow of rock material to the stationary edge of the glacier where it is dumped or deposited by streams. These deposits continue to build up until the ice front begins to move again.

There are several basic glacial depositional features that serve as the physical basis of Cape Cod and the Islands. Till deposited during a period of standstill takes the shape of a linear ridge parallel to the leading edge of the ice. The length, width, and height of the ridges are a function of the size and period of standstill of the glacier. This particular type of glacial deposit is called a terminal moraine if it was formed at the furthest extent of ice advance or a recessional moraine if deposited during a period of standstill as the ice margin retreated northward. Both terminal and recessional moraines form the basic structure or "backbones" of the Cape and associated islands.

During periods of both standstill and retreat, streams carrying heavy loads of sediment from the wasting ice form extensive deposits out in front of the ice margin. These deposits can take the form of wide, flat, gently sloping outwash plains, fan-shaped overlapping deltas, and knobshaped or conical deposits called kames laid down on or next to the melting ice. The deposits formed by meltwater streams are usually stratified and moderately to well sorted; that is, they occur in generally flat-lying or gently sloping beds with each bed being composed of sediments of one predominant grain size such as clay, sand, or gravel. Still another kind of landform produced by glacial action is a pit or depression in the land surface called a kettle. Most kettles in the Cape area are now filled with water and are seen as lakes. Kettles are formed when large blocks of ice left behind as the margin of the ice sheet retreats are completely or partially buried underneath glacial drift. When the blocks of ice finally melt, a hole or pit called a kettle is left in the landscape. An outwash plain commonly has several kettles located in it, and this type of plain is referred to as a pitted outwash plain.

PLEISTOCENE GEOLOGY OF THE CAPE COD AREA

Formation and Distribution of Morains Moraines

Glacial deposition in the area lasted several thousand years. The ice advanced from the north over the exposed land of the coastal plain surface. During glaciation, sea level was lower than present by about 450 feet (reported in Chamberlain, 1964) due to the large volume of water incorporated in the ice sheets. The coastline was far to the east and south of the present coastline. The furthest advance of the ice sheet reached a line about 20 miles south and east of the southern New England coast. There it stopped, and till and outwash deposits were laid down forming a long terminal moraine. This moraine forms the backbone of Long Island, Block Island, Martha's Vineyard, and Nantucket. Then, approximately 15,000 years ago, the ice front retreated northward to the area of present-day Cape Cod, where it again paused and formed a recessional moraine. A map of the two moraines is given in Figure 1-A2. The curving shape of the two moraines was caused by the effect of the coastal plain topography on ice advancing from the north,

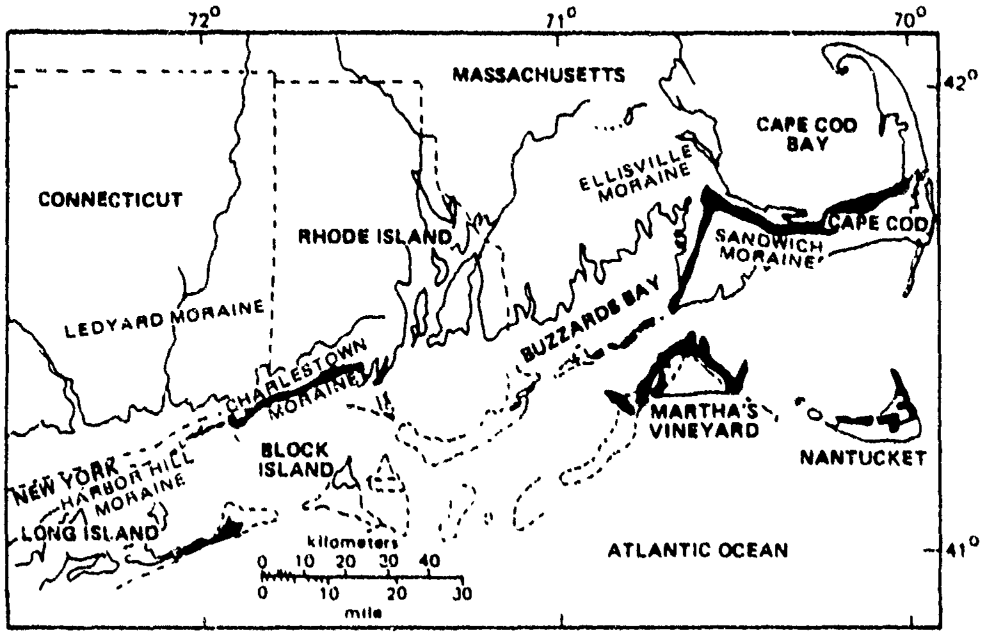

Figure 1-A2. End moraines of Wisconsin Glaciation in southeastern New England (Schafer and Hartshorn, 1965)

resulting in several lobes that brought down the materials forming the Cape and the Islands. The seaward extent of those moraines is unknown, but many of the offshore islands and submerged banks of the area are of glacial origin. Noteworthy examples are the Nantucket shoals southeast of Nantucket and Georges Bank lying farther east.

The recessional moraine forms a linear topographic high extending northeastward from the Elizabeth Islands along Route 28 to the Canal and then easterly along Route 6 on the north side of the upper and middle Cape to West Brewster where it dies away. The sharp bend in this ridge at the east end of the Canal is due to deposition of the moraine along the frontal margin of two distinct ice lobes, the Buzzards Bay and Cape Cod lobes, that intersected at the site of the present Canal (refer to Figure 1-A3). These moraines are composed of till.

Although these moraines form prominent ridges that outline the general shape of the upper and middle Cape, most of the body of the glacially formed Cape, including the outer arm extending from Orleans to Truro, was formed by meltwater streams depositing stratified drift on outwash plains in front of ice margins. Most of that part of the Cape lying east and south of the Buzzard's Bay and Sandwich moraines is a pitted outwash plain sloping down to Nantucket Sound from the higher elevations of the moraines.

Geological Formations of the Outer Cape

The outer cape is composed basically of meltwater deposits overlying discontinuous till laid down in the trough between the Cape Cod Bay and South Channel ice lobes.

As illustrated in Figure 1-A3, the Cape Cod Bay and South Channel lobes advanced to their terminal position and formed Martha's Vineyard and Nantucket. As the climate changed, the frontal margins of the lobes retreated northward to a standstill position at or near present-day Cape Cod.

The topography of the continental shelf greatly influenced the pattern of ice retreat during the waning of glacial ice in New England. The Buzzards Bay and Cape Cod Bay lobes were on the relatively shallow continental shelf while the South Channel lobe moved through deeper basins farther east. It was the occupation of these deeper areas that caused the South Channel lobe to extend and remain farther south of the Cape Cod Bay lobe during the general ice retreat when deglaciation occurred.

Following a long period of standstill, the Cape Cod Bay lobe retreated northwest leaving a large proglacial lake formed by the Cape Cod Bay lobe to the north, the South Channel lobe to the east, and drift deposits to the

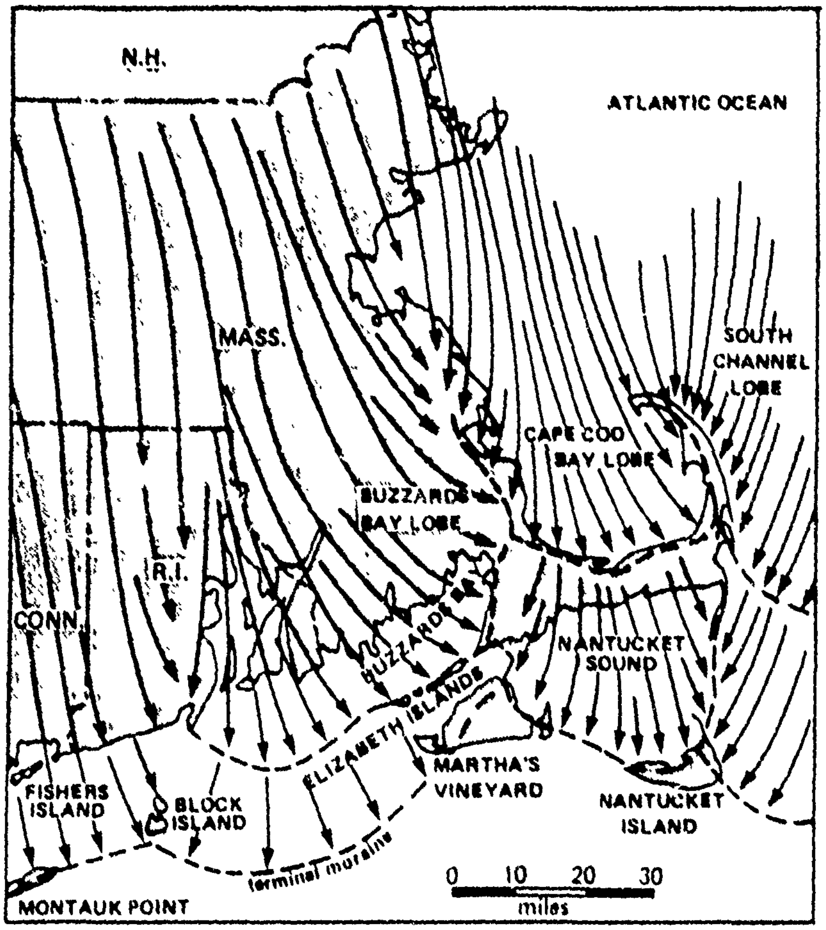

Figure 1-A3. Ice lobes of the Wisconsin Stage of Glaciation (Strahler, 1966)

south and west. Meltwater streams flowing off the South Channel lobe into the lake laid down the thick sequence of stratified deposits that make up most of the outer Cape.

These deposits rest on a basement that ranges from 370 to 900 feet below sea level. Till is found between the drift and the basement complex in the Orleans area and is of questionable occurrence further north (Strahler, 1966; Koteff et al, 1967; Oldale, 1968; and Oldale et al, 1971). The surface of these outwash deposits slopes downward from east to west. Several streams and abandoned glacial stream valleys such as Blackfish Creek near the Marconi Station and the Pamet River Valley in Truro also slope to the west. In the vicinity of Wellfleet, the gradients of these valleys have been found to be 38 to 87 feet per mile, almost four times the slope of the plain itself (Hartshorn et al, 1967). That the South Channel lobe is the source of the meltwater deposits is generally agreed upon (Koteff et al, 1967).

At least four different series of glacial deposits have been recognized on the outer Cape from Orleans northward. They are differentiated on the basis of lithology, elevation, and structural relations. Figure 1-A4 shows the distribution of these deposits which are termed the Eastham, Wellfleet, Highland, and Truro plains. Analysis of the structural and topographic relationship among these plains deposits has suggested a relative age ranking that allows inferences to be made regarding the manner in which the ice lobes retreated.

As the Cape Cod Bay lobe retreated northward and the proglacial lake discussed above began to form, the Wellfleet Plain was deposited in the interlobate area between the Cape Cod and South Channel lobes. The area later covered by the Eastham Plain was probably occupied by the ice of the South Channel lobe at the time of the Wellfleet deposition. The sediments of the Wellfleet Plain are chiefly gravelly sand and minor amounts of clay, silt, and gravel of mixed glaciofluvial and glaciolacustrine origin laid down in or next to the proglacial lake in Cape Cod Bay. As the ice retreated north, the younger Highland Plain and still younger Truro Plain were deposited by meltwater streams flowing westward from the South Channel lobe into the ever-enlarging proglacial lake. The Highland and Truro Plains consist of sand, pebbly sand, and clay. As northward retreat of the ice continued, meltwater streams draining the ice near Nauset Beach lighthouse laid down the Eastham Plain deposits. The lower, earlier Eastham deposits were formed in deltas at the edge of the proglacial lake. Later Eastham deposits were fluvial in nature, laid down by streams flowing westward from the retreating South Channel lobe. The Eastham Plain is similar to the rest of the outer Cape, being composed largely of sand and gravel with some clay and silt. As the ice on the South Channel lobe retreated from the Cape and the large proglacial lake drained, glacial deposition on the Cape Cod area was finished.

Glacial erosion, as well as deposition, also contributed significantly to the present topography of the outer Cape. The several abandoned westward-sloping stream valleys that occur along the outer Cape in the Wellfleet-Truro

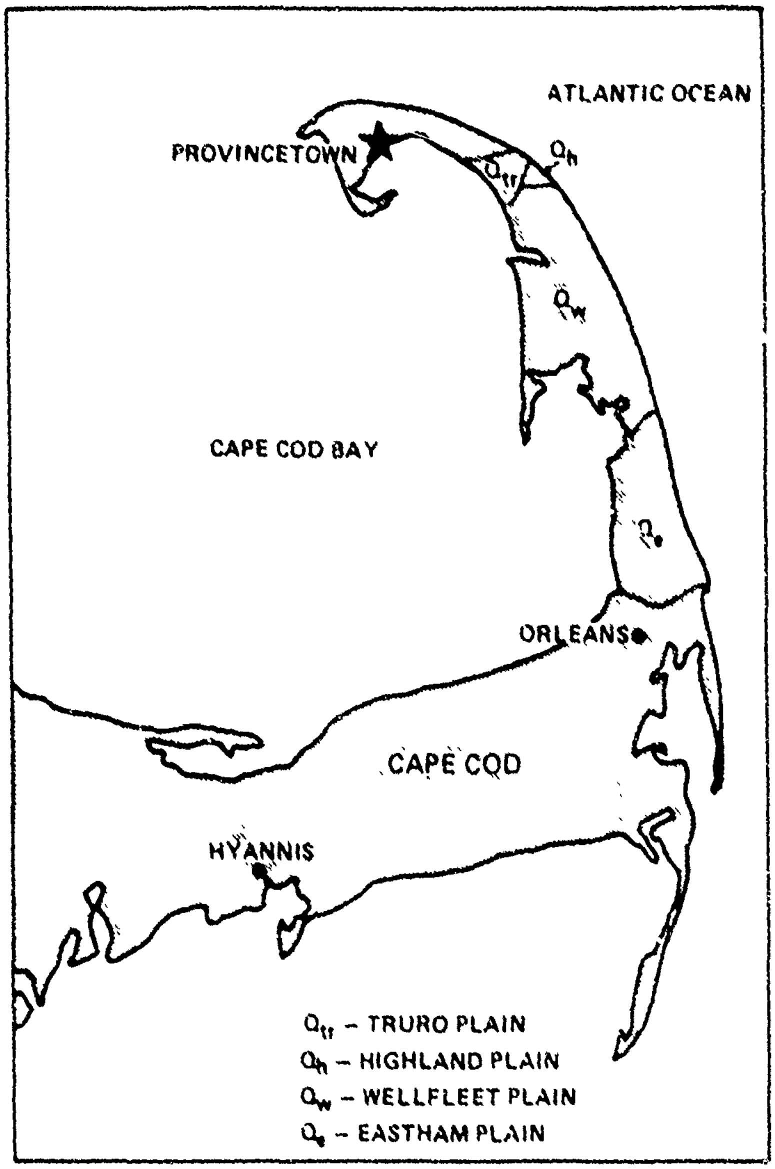

Figure 1-A4. Plains deposits, outer Cape

area are due in part to erosion by late glacial streams. Prime examples are the Little Pamet and Pamet River valleys and the dry valleys or hollows such as Great Hollow in Truro and LeCount Hollow in Wellfleet. These valleys were most likely formed shortly after the ice had left the immediate vicinity of the Cape but while it still furnished meltwater to the plains deposits. The powerful streams, fed by the wasting ice, cut through the easily eroded unconsolidated sediments and formed valleys with gradients markedly steeper than the land surface. The many ponds and lakes dotting the area such as Great Pond, Gull Pond, and Slough Pond are kettle holes, formed when large, buried blocks of ice melted to form the depressions now filled with water.

Although direct effects of glaciation ceased on Cape Cod with the complete retreat of ice from the area approximately 14,000 years ago, indirect effects continued fo, several thousand years. At the time glacial ice left Cape Cod, eustatic sea level (a worldwide change in sea level related to the amount of water incorporated in ice caps) was about 400 feet below its present level (Milliman and Emery, 1968), and the shoreline was approximately 10 miles east of its present location. The cause of the sea level decline was the retention of water by glacial ice. As the glacial ice melted, the seas rose again. According to Zeigler et al (1965), the sea reached the glacially formed Cape about 6,000 years ago. Marine erosion occurred as waves eroded the land. Sea level continued to rise until it approached within -7 feet of its present level about 2,100 years ago (Redfield, 1965). Since that time the rate of sea level rise has been reduced.

As sea level stabilized, marine erosion of sea cliffs on both sides of the outer arm and the process of land sculpting and modification began. These processes are still at work. Figure 1-A5 illustrates what the outline of eastern Cape Cod might have looked like after sea level reached the Cape and before wave and wind erosion modified it to its present appearance.

POST-GLACIAL HISTORY AND EVOLUTION OF PRESENT-DAY APPEARANCE

Comparing the outline map in Figure 1-A5 with the present-day shape of Cape Cod shows that significant landscape changes have taken place during the last few thousand years. These changes were caused primarily by the work of wind and water eroding and redepositing the unconsolidated sands and gravels of which the Cape is composed. This section discusses processes that have modified the outline of the Cape from early post-glacial times until today. Illustrations of land forms such as the great hook near Provincetown, The Highlands of Truro and the long spits such as Coast Guard and Nauset Beaches are presented and discussed in detail.

Wave Formation and Mechanics

Water waves direct large amounts of energy toward the land, causing much erosion and movement of earth material. King (1959) summed up the effect of waves on shorelines with the words, "A beach is one of the most variable of land forms; it can be there one day and gone the next." Large storm waves have been estimated to batter cliffs with a pressure of 6000 pounds per square foot. A wave measuring 10 feet high and 100 feet long can exert pressures of 1675 pounds per square foot. Zeigler and Tuttle (1961), in their studies of the outer Cape beaches, stressed that wave action can move enormous amounts of material in minutes. They reported that a spit near High Head in North Truro was moved 75 feet to the northwest between 11 March and 12 March 1957. Another spit at the same location was moved 25 feet between 27 March and 28 March of the same year. Figure 1-A6 shows that the power of wave erosion is substantial, particularly when directed toward the unconsolidated sands and gravels of Cape Cod.

In order to understand how waves can erode the beaches of Cape Cod so quickly and so powerfully, a brief discussion of wave mechanics is in order. Ocean waves are formed by wind dragging over the water surface. In this manner wind energy is transferred to the water, and the waves carry this energy toward the land where it is expended against the shoreline materials. In deeper water, waves produce orbital motion of the water. As the wave forms reach shallower water, the orbital motion of the water starts to "drag bottom" and a frictional force acts between the water and the sand or gravel of the ocean floor. This movement forms the ripples seen in the sands exposed at low tide or felt by the feet of bathers as they wade out from shore. As a wave approaches the shoreline, it becomes narrower and higher. Finally, the wave form becomes so high that it is unstable, and the wave breaks. The water forming the wave at that point is thrown forward. This process of wave breaking transforms the energy of wave motion into the kinetic energy of moving water which then does 'work' on the shoreline. The swash (the rush of water moving up on the beach) runs back down the beach face as backwash.

The enormous amount of energy carried by the wave and put to work on the shoreline expends itself in several ways. It carries sand and pebbles seaward and landward on the slope of the beach and also transports material along the margin of the beach. In addition, waves striking at scarps, beaches, or any other structures (natural or man-made) will impact with great force causing substantial erosion. Waves are continually eroding, moving, and redepositing the materials of the shoreline. However, it is the storm waves that produce the most significant erosion changes.

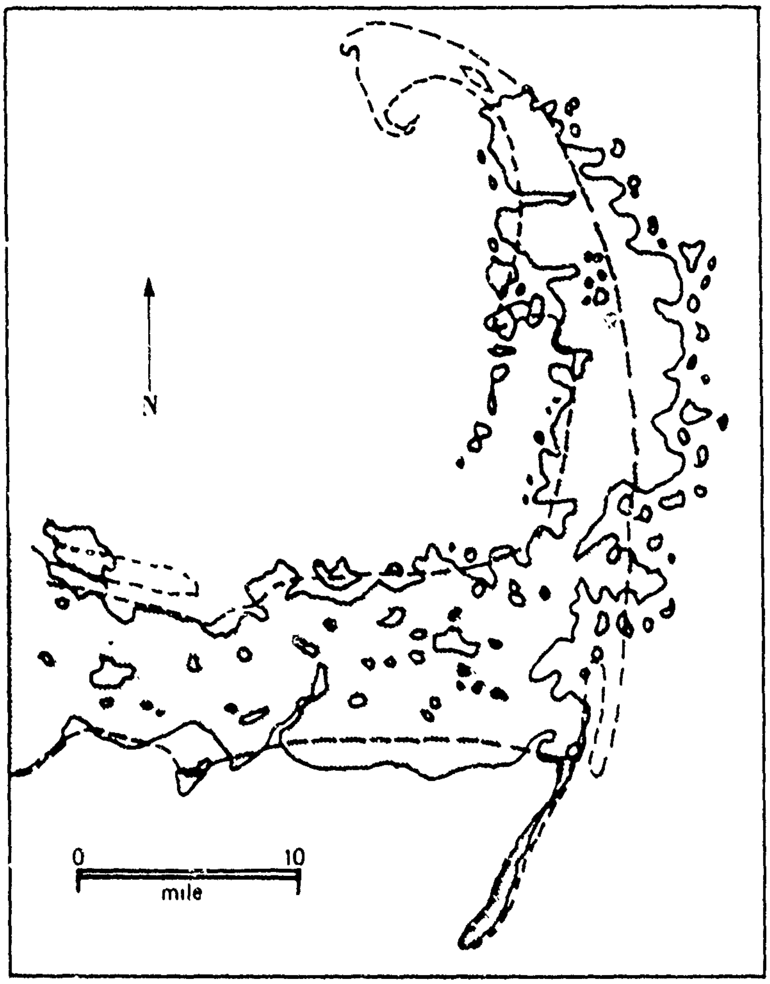

Figure 1-A5. Hypothetical map of early Cape Cod (After Davis, 1896)

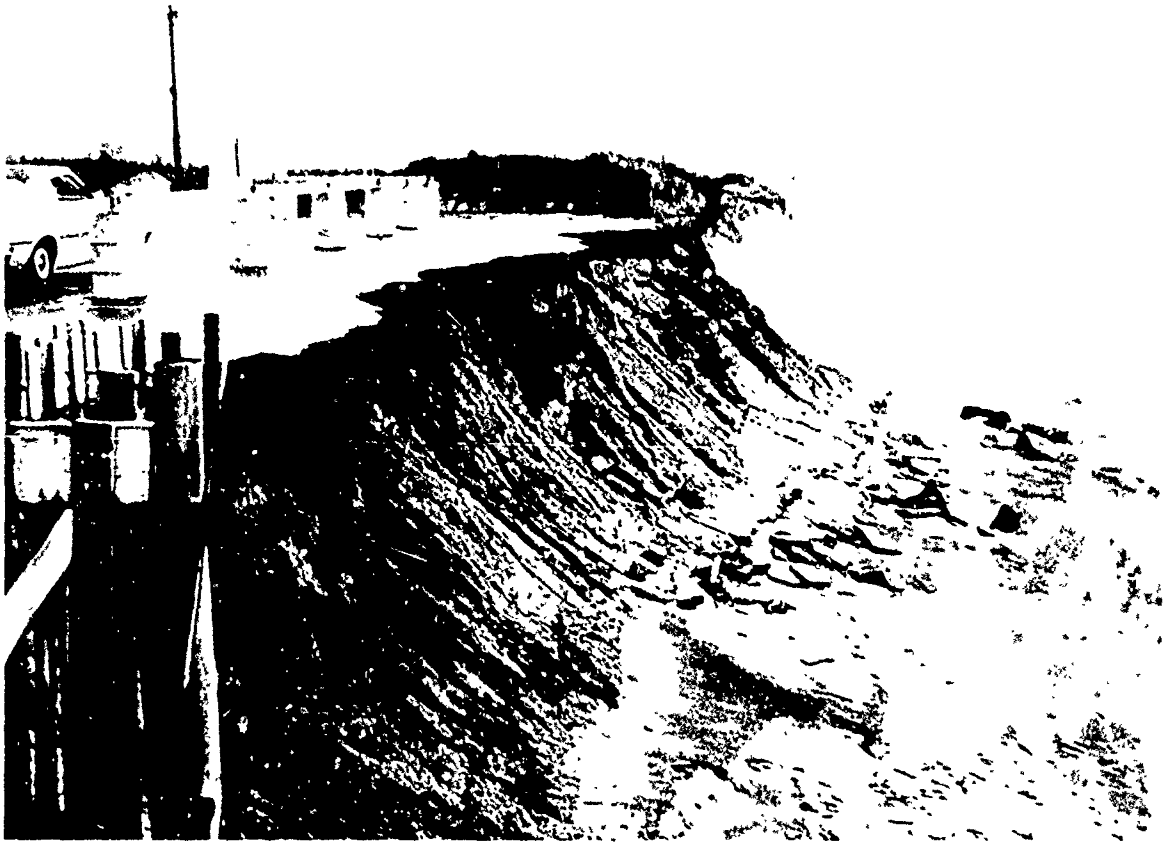

Figure 1-A-6. Storm erosion, Coast Guard Beach (courtesy of John Fisher)

Work of Waves

Erosion

Waves began eroding the glacial drift deposited in the vicinity of present-day Cape Cod as soon as the area became ice free. Zeigler et al (1965) postulate that the Gulf of Maine became ice free approximately 12,000 years B.P. Waves (generally from the northeast) then began to wear away the early Cape. As sea level continued to rise, the area of Georges Bank became submerged about 6,000 years ago, allowing ocean waves to reach the Cape from the southeast. Sea level at that time was about 10 fathoms below present sea level. The rising sea continued to encroach upon the sands and gravels of the Cape until several thousand years ago. Although the outline of the early Cape as portrayed in Figure 1-A5 is conceptual in purpose, the coastline at that time was almost certainly irregular and embayed in a fashion similar to that shown. Rising sea level encroaching over the uneven surface of the glacial drift deposits would have created such a drowned coastline, quite different from the even, gently curving outline of the present-day outer Cape. Sea level has continued to rise, at a greatly reduced rate, but the shoreline changes have been due most directly to erosion by wave and wind action rather than encroachment of the sea.

Wave action has not only changed the shape of the shoreline but also cut it back a distance of approximately 2 miles during the past three or four thousand years. The enormous quantity of sand and gravel removed by erosion was redistributed and redeposited to form the beaches that border the outer Cape as well as the great hook or curved spit of Provincetown and other features, such as the long straight spits of Nauset Beach and Monomoy Island.

As the wave fronts approached the irregular coastline of the original Cape, wave refraction caused the erosive power of the waves to be concentrated at the headlands. The waves tended to slow down in the shallow water off the headlands. The resultant reduction in wave velocity caused the wave front to bend around the headland and focus its energy at that point. As the waves broke against these headlands, the swash of the powerful waves, especially the higher storm waves, cut deeply into land. The backwash removed the eroded material and quickly a steep scarp or marine cliff formed as the headlands retreated. Continual marine erosion of headlands has resulted in an almost uninterrupted marine scarp extending along the outer beach from just north of Nauset Bay to Highland Light in North Truro. Figure 1-A7 shows the location and some representative heights of this scarp. These marine cliffs are not cliffs in the true sense of the word with sharply rising vertical or near vertical faces; rather they slope at approximately 35 degrees from the horizontal. The low cohesion of the loose unconsolidated sand and gravel prevents them from maintaining a steeper slope.

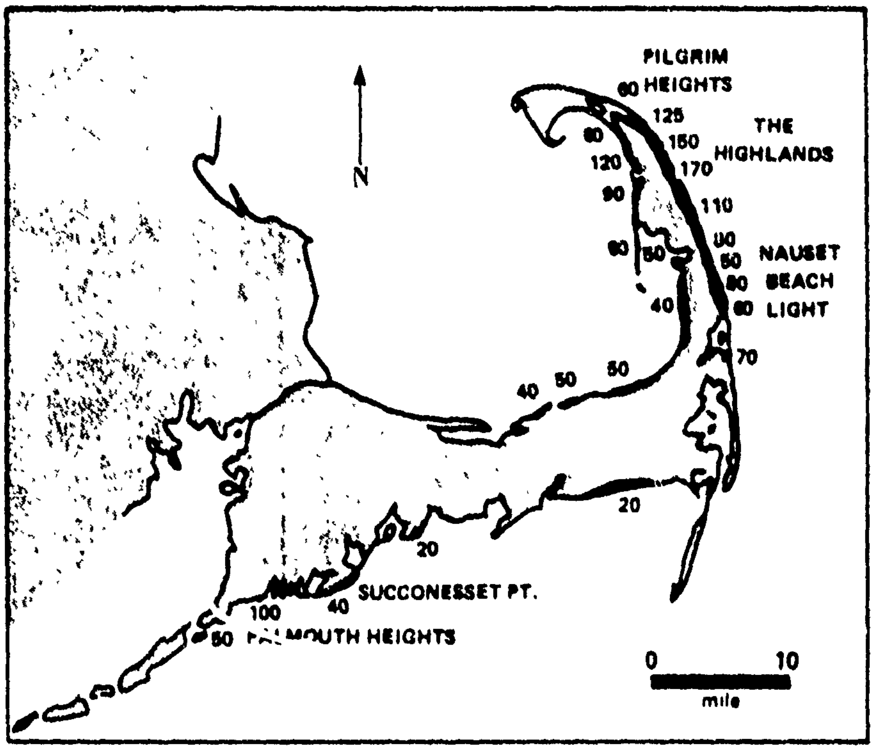

Figure 1-A7. Principal marine scarps of Cape Cod (Heights in feet)
(After Strahler, 1966)

The rate at which the scarp is being worn back has been the subject of speculation. Marindin (1891) concluded that most of the erosion occurs during winter storms and that the average rate of scarp retreat is 3 feet per year. Zeigler et al (1964) determined the rate to be 2-1/2 feet per year. The severe impact and significance of this extremely rapid erosion can be illustrated by some representative examples. At Highland Light, which overlooks the marine cliffs of Truro, severe winter storms have eroded the cliffs by as much as 8 feet in a single year. Chamberlain (1964) reported that only about 3 or 4 acres of the original 10-acre site purchased in 1787 by the Government to house the Highland Light remain, the rest having been lost to erosion. In the area of Nauset Light in Eastham, continued beach erosion and scarp retreat have forced the construction of several lighthouses, each one further inland. In 1839 three brick lighthouses, the "Three Sisters of Nauset," were built, and by 1892 erosion had caused all of them to fall into the ocean. It is only a matter of time before the present lighthouse, constructed in 1923, succumbs to the forces of the sea.

Figure 1-A8 shows a plaque placed by the National Park Service at Nauset Light Beach telling the story of the Three Sisters. Figure 1-A9 shows the present lighthouse in relationship to the cliffs at Nauset.

Most of the sand and gravel eroded from the original glacial deposits is reworked and redeposited to form beaches, offshore bars, and other depositional land forms seen on the Cape today. The shape and appearance of these deposits at any given time is in momentary response to the constantly varying forces of wind and water acting on them. If the energy and force of the waves were constant in magnitude and direction, then the beaches of the Cape would reach a state of dynamic equilibrium and change would be easily predicted. These forces are not constant, however, and thus the beaches and other depositional forms are always in a state of flux.

Beach Formation and Migration

In spite of the everchanging wave conditions, certain well-defined beach features can be identified on outer Cape beaches. The relatively steep slope over which the swash and backwash flow is called the <u>foreshore</u>. At the base of the foreshore, a low deposit of coarse, textured material like gravel or small cobblestones commonly occurs. Seaward of this bar is the <u>offshore zone</u>, which is characterized by a somewhat gentler slope than the foreshore. At the top of the foreshore there is a flat terrace called the <u>berm</u>, which is built up of sand brought up and deposited by the swash. Landward of the berm there may be a <u>scarp</u> if the beach is in front of a higher area, or there may be a zone of sand dunes.

The size and placement of the foreshore and berm will vary depending on the energy of the waves striking the beach. A storm wave will tend to erode a berm, cutting the beach back and moving the foreshore landward. This cutting back of the beach is called <u>retrogradation</u>. On Cape Cod beaches, depending

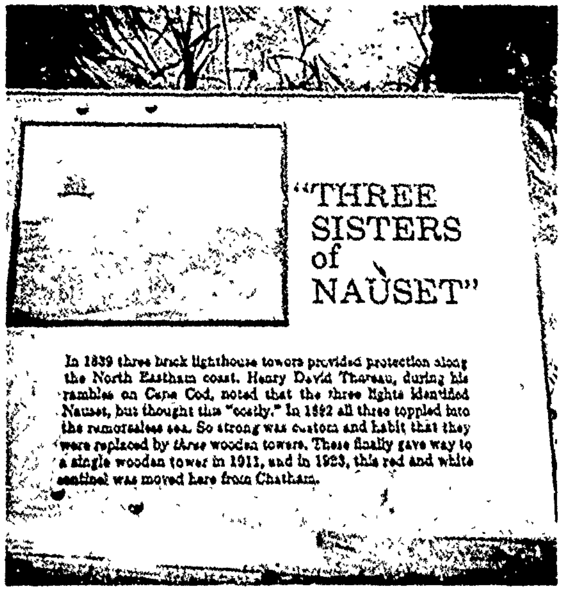

Figure 1-A-8. Plaque at Nauset Light Beach

Figure 1-A-9. Nauset Light, 1976

on the season, there may be two berms developed, a summer berm and a higher, winter berm situated more landward. Long, low waves such as those of a quiet swell tend to deposit sand on a beach causing the berm to build seaward, a process called progradation. Thus the summer, with its generally quieter wave conditions, is usually a time of progradation and the formation of the summer berm. Short, steep, choppy, storm waves tend to transport sand seaward and cause retrogradation. Winter storms will destroy the summer berm and cause the beachfront to move inland where a winter berm is constructed. As summer returns, progradation takes place and the cycle starts again. Figure 1-A10, a photograph of the beach at Nauset Light in late spring before the summer berm was formed shows a winter berm and foreshore. The berm boundary is marked by the line of sunbathers.

Studies by the Woods Hole Oceanographic Institution (Zeigler, 1956) of beaches near Highland Light and Nauset show the beaches were driven landward significant distances during the 33 month period of the study. The presence of peat deposits on the seaward side of Nauset Spit is further evidence of landward migration of the beach.

Littoral Drift

Another method by which the eroded sediments of the Cape are moved and redeposited to create land forms is the process of shore or littoral drifting. Littoral drifting is the combined term for sediment transport by beach drifting and longshore currents. As waves strike a beach there is usually an angle between the wave front and the shoreline. On the outer beaches of the Cape, the waves generally approach from the southeast in the summer and from the northeast during winter storms, thus making oblique angles with the shore. Beach drift occurs due to the different directions in which the swash and backwash transport sediment. The swash of these oblique waves moves over the foreshore in the same direction as the wave. The backwash, however, which is controlled chiefly by gravity, tends to move down the beach face more directly. The sand and pebbles carried up and down the beach in this manner are moved a net distance along the beach. Figure 1-A11 illustrates this process. Although the net amount of beach drift from one wave might only be an inch or so, the cumulative effect of this process creates a steady movement or drift of sediment along the beach.

Longshore currents, the second component of littoral drift, are formed in the shallow water just seaward of the foreshore and flow parallel to the shoreline in the open end of the "V" made by the wave fronts and the shore. (See Figure 1-A11.) Water moving in these longshore currents is capable of transporting sand and gravel along the shore in the same direction as the related beach drifting. Although wind directions and velocities are quite variable in the vicinity of the outer Cape, wind and wave directions during the year can be analyzed and a direction of net transport determined.

Littoral drift, which is prevalent along the outer beaches of the Cape, exhibits two distinct directions: north to Provincetown and south to Nauset Beach and Monomoy Island. The cause of this divided movement and the location

Figure 1-A-10. Winter berm and foreshore, Nauset Light Beach

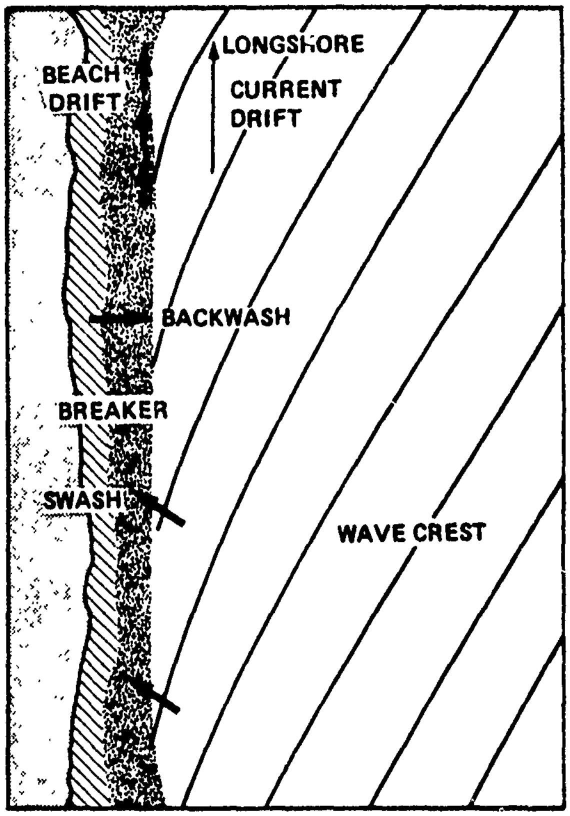

Figure 1-A11. Littoral drift (Strahler, 1966)

of the nodal point where the net flow of sand changes from north to south have not been determined. Hartshorn et al (1967) placed the dividing line "... somewhere near the center of the outer Cape." Schalk (1938), based on his study of sediments of the outer beach, suggested that the nodal point might be opposite the Pamet River. Fisher (1976) discussed a dynamic morphologic/sedimentologic model that suggests that the point might be located at Newcomb Hollow Beach in Wellfleet. Cornillon et al (1976) found that the location of the nodal point, which depends on the direction from which the waves approach the coast, varies from east of Race Point southeastward to approximately Newcomb Hollow Beach when the waves have a northerly component (NW, NNW, N, NNE, NE and ENE). For easterly and southerly winds (E, ESE and SE), they located the nodal point between Nauset Harbor and the entrance to Chatham Harbor. For long-term average conditions, the nodal point was located near LeCount Hollow Beach.

Formation of Spits and Bars - Nauset Beach

The direction of littoral drift accounts for the southerly trending spits and bars below Wellfleet and the large hook of the Provincelands to the north. Sand transported along the coast by littoral drift eventually reaches a spot where the shoreline bends landward, for example, at the mouth of a bay or where the main body of the land may curve sharply as in the vicinity of Chatham. When drifting sand encounters these bends in the shoreline, it usually continues in a straight line. The transported sand tends to settle as the water deepens forming a long, narrow subsurface bar. This depositional process is continued with the earlier formed portion of the bar serving as a foundation for more sand to be carried still farther out from land. Wave action shapes and builds up the bar until it emerges above water level when it is termed a spit. As drift proceeds, the spit is elongated until it either reaches land or is halted in its growth by some combination of wind and wave mechanics. Figure 1-A12 diagrammatically illustrates this process. As the spit grows to a sufficient length, wave refraction causes the end of the bar to be curved landward. The spit is then termed a recurved spit.

Nauset Beach is an excellent example of a recurved spit (Strahler, 1966). Sand transported by littoral drift south from the eroding cliffs of Eastham and Wellfleet was deposited out into Nauset Bay extending the smooth line of the beaches at the foot of the scarp. The spit has grown southward until it has almost completely blocked Nauset Bay from the sea. A similar process constructed a spit south from Nauset Heights, forming the barrier beach that now encloses Pleasant Bay. Monomoy Island, although having a more complex origin than Nauset Beach, is also a spit constructed from sand transported south from the eroding headlands. In the winter of 1957-58, when it extended 7 miles out from Morris Island, Monomoy spit was breached by storms and is now separated from the mainland by a channel between Nantucket Sound and Chatham Harbor.

The effect of wave erosion and deposition on both Nauset Beach and Monomoy Island is continuous, and the shape and appearance of these spits are constantly changing. It is estimated that Nauset Beach is both retreating landward at a rate of 3.0 feet per year (Strahler, 1966) and growing at its southerly tip by about 250 feet per year. Examination of old maps reveals that in 1860

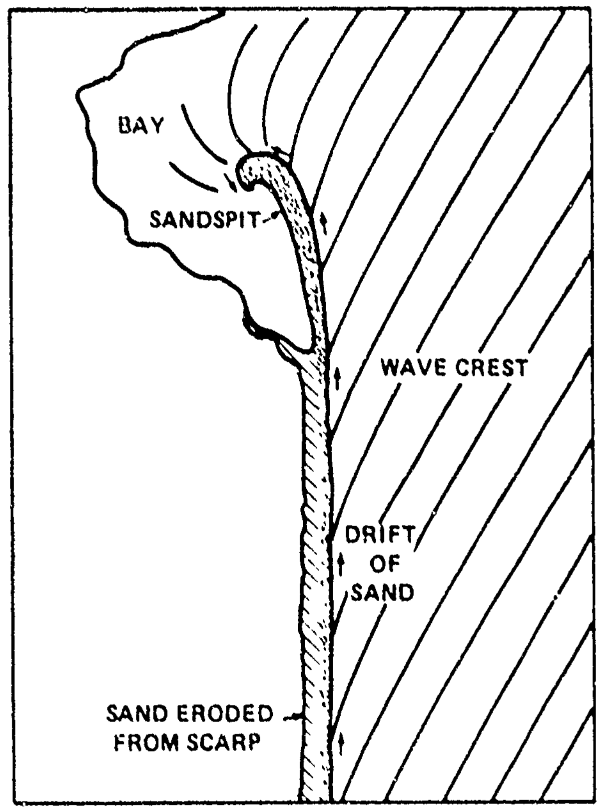

Figure 1-A12. Sandspit formation (Strahler, 1966)

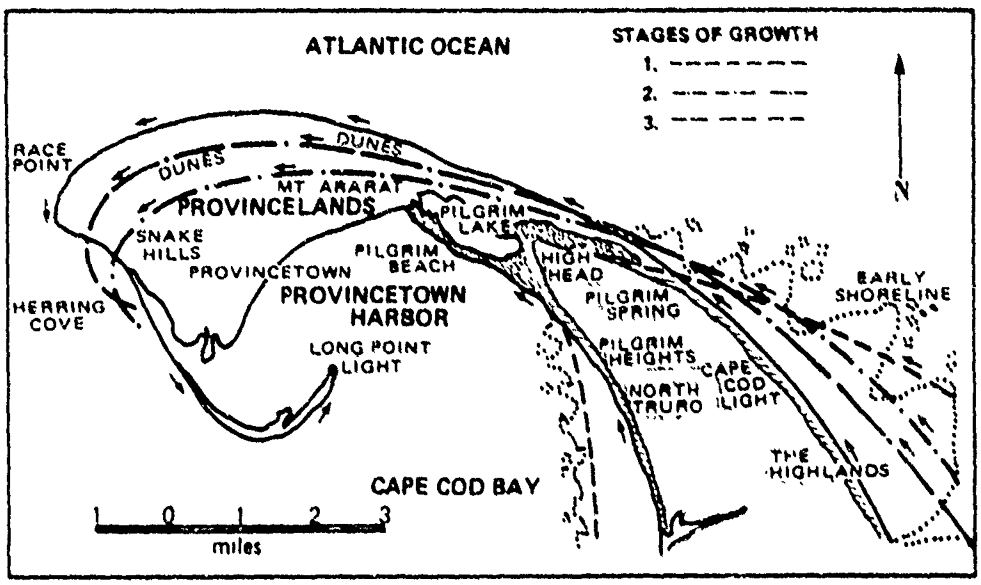

Figure 1-A13. Growth of Provincelands (Strahler, 1966)

the Chatham Harbor inlet to Pleasant Bay was located opposite Allen's Point and since that time has migrated about 4 miles south to its present location. In addition to the dominant trend of southerly movement, parts of Nauset Beach are changing and extending in other directions. A comparison of U.S.G.S. and Coastal Survey maps from the past 120 years shows that the south spit at Nauset inlet apparently migrated approximately 5,000 feet northward between 1856 and 1956 and during that same period retreated landward into Nauset Bay at an average annual rate of 4 feet per year (Zeigler et al, 1956). Since 1956, the spit has again undergone radical changes, which are discussed in the Shoreline Changes Section.

Monomoy Beach is also being extended by sand originally eroded from the scarps north of Nauset Light and transported south by littoral drift. Characterized by rapid buildup, Monomoy Point grew southward at an average rate of 157 feet per year between 1856 and 1868 (Strahler, 1966). The delicate balance between the various components of a littoral environment is well illustrated by the breaching of Monomoy near Morris Island in the winter of 1957-58. As a result of that event, wave and water patterns changed and sediments were redistributed. The natural channel into Chatham Harbor shoaled, and an offshore bar began to form at the mouth of the inlet. The 18- to 20-foot depth of water was reduced to about 4 to 5 feet and presented serious navigation problems.

The preceding discussion has dealt with the dominant trends of erosion and deposition present on the middle and lower (southerly) sections of the outer Cape. The middle section, from Eastham north to Truro, has undergone frontal erosion by wave attack resulting in the formation of a series of marine cliffs or scarps which have continually retreated at rates approximating 3 feet per year. Enormous quantities of eroded sand and gravel have been transported south by littoral drift and deposited to form south-trending spits and barrier beaches such as Nauset Beach and Monomoy Island found on the lower reaches of the outer Cape. In addition to these larger landforms, obvious on even the smallest maps of the Cape, there are countless smaller beaches, sand bars, and other depositional structures that have been formed by various agents acting on the sand transported south.

Formation of the Provincelands

The third major landform of the outer Cape (the other two being the previously discussed scarps of the central portion and the south-extending spits of the lower part) is the Great Hook of the Provincelands. This landmass, located at the outer end of the Cape, is completely post-glacial in origin and constructed of material deposited long after glacial ice had retreated from the area. In a very real sense, the Provincelands can be thought of as an addition to the original landmass. The outline of the north end of the ancestral Cape, as it existed just before the building of the Provincelands about 6,000 years ago, is defined by the well-preserved scarp extending from Pilgrim Heights to Head of the Meadow Beach (Figure 1-A13).

The origin of this historical part of Cape Cod has long been a subject of interest. With the exception of a tentative hypothesis regarding an original island of glacial deposits around which the hook was constructed (Smith and Messinger, 1959), researchers agree that the Provincelands area was constructed

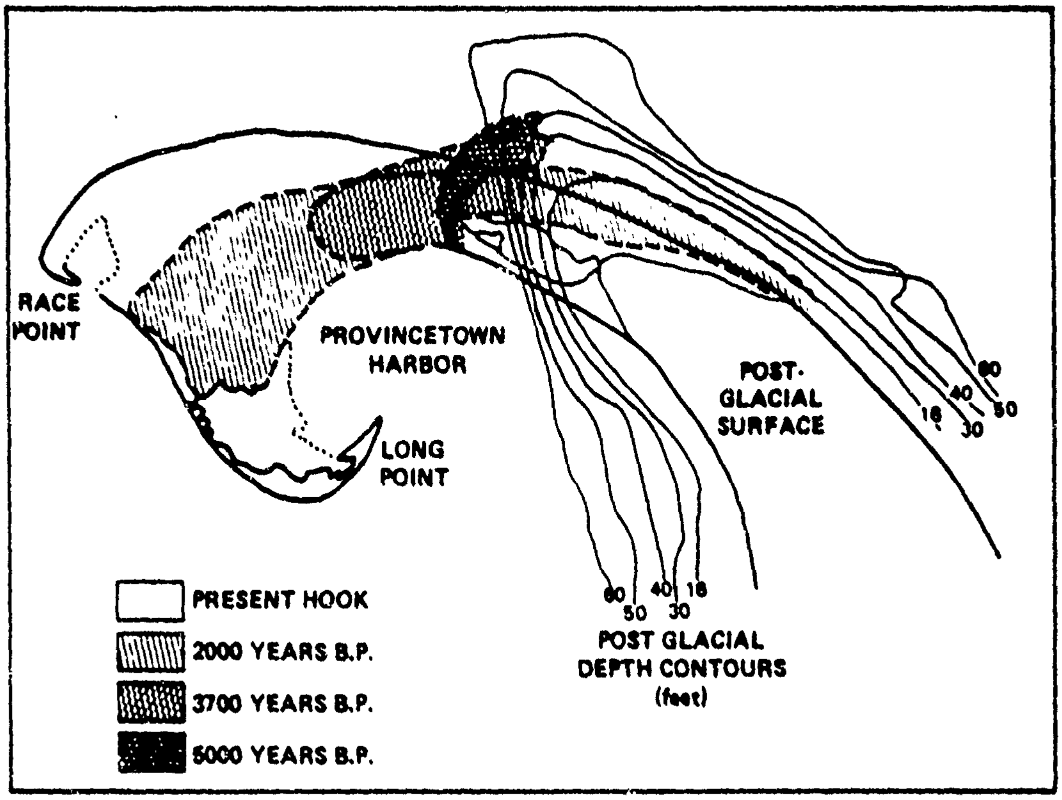

Figure 1-A14. Provincelands hook showing successive positions of older shorelines (Zeigler et al, 1965)

from sand transported north from the original body of the Cape by littoral drift. Material eroded from the Highland cliffs and scarps near Truro entered the littoral drift north of the nodal point which separated the northerly and southerly flow and supplied sand to the Provincelands. Sand was carried in a northwesterly direction and deposited in a series of successive spits on the north side of the original spit, thus forming the presentday Provincelands with its east-west trending linear sand ridges.

A more recent study of the problem by Zeigler et al (1965) generally agrees with Davis (1896) and other authors concerning the successive buildup of the hook by accretion of sediments transported north by littoral drift from eroded highlands. Stratigraphic information reported by Zeigler supports the hypothesis of an entirely post-glacial history for the hook and rejects the glacial island hypothesis cited earlier.

Figure 1-A14 shows the growth of the Provincelands as postulated by Zeigler (1965). Beach surveys have shown that the northern shoreline of the Provincelands Hook has advanced seaward at an average rate of about 2 feet per year indicating that the hook is still growing by accretion.

Formation of Salt Meadow and Pilgrim Lake

As the first snad spits grew out from the original Cape along a line extending from the scarps near Highland Light (see Figure 1-A13), a barrier beach was formed and a narrow lagoon occupied the area between the barrier beach and the High Head marine scarp. Since its original formation, the lagoon has been filled in with sand and tidal marsh deposits to form a salt marsh or salt meadow.

Pilgrim Lake just west of Salt Meadow was originally a bay called East Harbor that was protected from Cape Cod Bay by a narrow bay mouth bar. This bar was a spit that grew northward as sand derived from the original marine scarps at Pilgrim Heights was moved north along the inner or Cape Cod Bay side of the Cape. The spit extended northward and was joined to the land by a man-made dike near Mayflower Heights in 1869 thus sealing off East Harbor from Cape Cod Bay. The new lake so formed was called Pilgrim Lake, and the spit which reached across the mouth of the old bay is now called Pilgrim Beach. Due to the density relationships of fresh to salt water, the surface of Pilgrim Lake is now about 2 feet higher than the surrounding sea level.

Tidal Currents

Tidal currents set up by the rise and fall of the tides also affect the outer beach. Although exerting a relatively minor impact when compared with the work of waves, tidal currents nevertheless play an important part in shaping the outer beach. As the tide rises, a landward motion of water called a flood current is induced through inlets into bays and estuaries. As the tidal water

begins to recede, the current motion is reversed and water flows seaward as an ebb current. These flood and ebb currents, which can reach speeds of 3 to 5 knots in some harbors and inlets, erode and transport material. Tidal currents often keep inlets open by preventing spits and bay mouth bars from sealing off the harbors across which they are being built.

Ebb and flood flows also have a depositional function. They transport clay and silt from the more turbulent waters offshore into the quiet, low-energy environments of harbors and lagoons. The clay and fine silt settle in the quiet water and build up mud deposits on the floors of the bays. These bottom muds are cohesive and difficult to dislodge or disturb. The layers of accumulated mud eventually build up until they approach sea level, and a mud flat that is exposed at low tide and covered by shallow water at high tide is formed. Marine vegetation such as eel grass helps to anchor the mud as it accumulates and contributes to its organic content. Once the buildup of mud deposits reaches sea level, salt-tolerant plants, which trap more silt and clay, begin to grow. The combination of plant grasses and further sediment accumulation results in a tough, erosion-resistant, vegetal mat that reaches approximately the level of high tide. At this point in its evolution, the mud flat is called a salt marsh. Salt marshes are found on the bayside of Nauset Beach (both Nauset Bay and Pleasant Bay) and on the west side of most of Monomoy Island.

Some effects produced by tidal currents are detrimental to the environment. Sediment transported by tidal currents can bury shellfish beds and create navigational hazards.

Wind

Erosion

Wind is another vital factor influencing the formation of Cape Cod. As was mentioned previously, wind is the dominant force driving the water waves that are constantly working to erode and reshape the coastline. In addition, wind also acts independently of the water, continually moving material and daily changing the surface features of many parts of the outer Cape. When discussing the action of wind as an independent agent of erosion, the term eolian transport or eolian erosion is commonly used.

The transporting capacity of wind is limited to fine-grained unconsolidated material which is not anchored to the surface by vegetation. Because of their composition, the beaches and other sand areas of the Cape are subject to eolian erosion on a large scale. Wind transports material by lifting particles into the air or rolling them along the ground. Sand and silt grains are carried by the winds in a series of low leaping arcs or jumps generally reaching a height of 1 or 2 inches (or higher in stronger winds) covering a horizontal distance of perhaps twice that amount. This mechanism, termed saltation, also

causes a slow rolling movement of grains along the surface by a process known as creep. As a particle descending from its saltation leap strikes the ground, the force of its impact will force other grains to be dislodged and move along the ground. The cumulative effect of this very rapid movement causes a thin blanket of sand to be continually transported over the surface wherever the wind is blowing. Finer material such as clay and silt particles are also picked up by the wind, held in suspension, and transported long distances.

The amount of material carried by eolian transport is dependent upon the force of the wind and the availability of the particles. On a calm day little sand is transported by the wind, while on a blustery windy day a substantial amount can be moved in a short period of time. The presence of vegetal matter or some other blanketing material also has an effect on the amount of material moved. Less material is picked up, and vegetation such as beach grass can filter the sand from the air. In areas where salt grass, pitch pine, or other plants are well established, there is little movement of sand even on the windiest of days. On the other extreme are the beaches and sandy areas where the absence of plants or other vegetation allows the sand to be picked up freely and transported by the wind.

Dunes

Origin - The most visible results of eolian erosion and transport on Cape Cod are the several dune areas found on Monomoy Island, Nauset Beach, the Old Camp Wellfleet area, and the Provincelands, the last being the largest in size (see Figure 1-A15). These dunes are composed primarily of sand that originated from the beaches bordering the dune areas.

As sand is blown inland from the surface of the beach, it accumulates around various obstacles landward of the berm, provided there is sufficient room. Naturally, no dunes form where headland erosion and consequent formation of marine scarps is occurring. The dunes, which are built up from sand blown in from the beach, often assume the form of a low ridge of irregularly shaped hills and low areas.

If the topography permits and if little or no vegetation has taken root in these foredunes, they tend to migrate inland. Wind carries sand up the generally more shallow slope of the windward face and down the steeper slope of the lee side, causing the dune to move slowly in the same direction as the wind. Dunes generally migrate in this manner until they become fixed or stabilized by sufficient permanent growth of trees, plants, or grass that holds and protects the sand from the winds. Stabilization usually occurs when the dunes have migrated far enough inland to be out of effective range of the prevailing onshore salt-carrying winds. If left undisturbed, the stablized dune acquires a thick mantle of plant coverage. Stabilized dunes are positive environmental factors, serving as wind breaks and barriers to drifting sand as well as protection against water from extremely high tides and storm waves. In most cases, a migrating or "live" dune is a hazard to the area. In the Provincelands area the contrast between migrating and stabilized dunes can best be seen. It is also in this area that the most substantial damage by migrating dunes has been recorded.

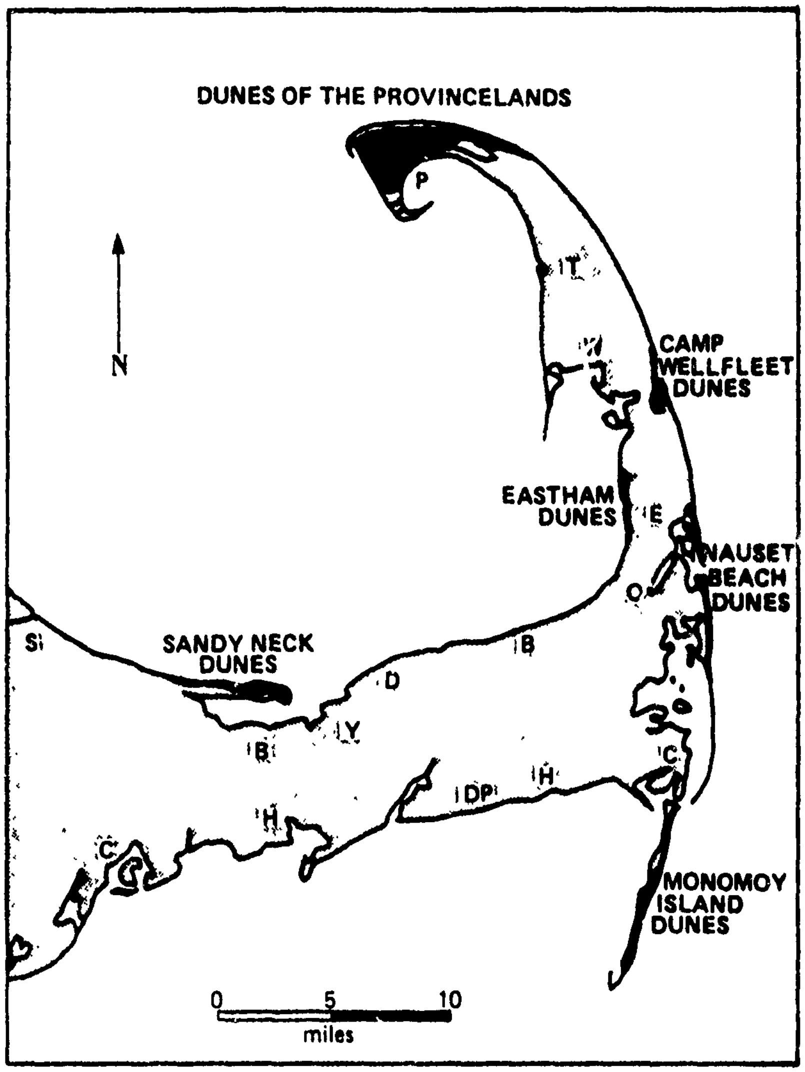

Figure 1-A15. Dune areas, Cape Cod (Strahler, 1966)

Nauset Beach has been overtopped by storm waves in many places. These washovers denude the dunes of vegetation, exposing them to eolian erosion. This process leaves them more vulnerable to future washovers. It has been estimated that between the years 1943 and 1968 over one million cubic yards of sand were blown into Pleasant Bay (U.S. Army Corpos of Engineers, 1968). This accumulation contributed to shellfish bed cover and the formation of navigational hazards.

Dunes History and Morphology of the Provincelands - Dunes of the Provincelands are predominantly parabolic dunes. This particular name is applied because the shape of the dunes resembles a bow-shaped mathematical curve known as a parabola. These dunes form in areas lacking vegetation when wind erosion creates a semicircular blowout. Sand piles up around the margin of the blowout in a curved ridge-shaped dune facing into the direction of the wind. If plant growth is not established and if the wind continues to blow, the dune will migrate in the direction of the wind as sand is moved up the shallow windward face and down the steep slip face. The migrating dune tends to move over any area in its path whether it be a forest, salt marsh, or human habitation. The best-developed parabolic dunes in the Provincelands are located along the outer shore north of Pilgrim Lake. The overlook above Head of the Meadow on the Pilgrim Spring Trail is an excellent place from which to view these dunes. Other dunes in the area such as the Mount Ararat dune fields to the west of Pilgrim Lake are not as well developed as those just mentioned, being more open and semi-circular in shape. The Mount Ararat dunes are actively migrating, and they can be easily seen as one proceeds west along Route 6. The dunes are continually encroaching upon this highway and actually present a hazard to motorists, especially during heavy winds.

Examination of the United States Geological Survey (U.S.G.S.) topographic map of the Provincetown quadrangle shows that the main body of the Provincelands exhibits divisions of dune morphology. North of an approximate east-west trending chain of ponds, the dunes appear as a series of parallel linear ridges, and south of this boundary line the dunes are more irregular and lose their linearity. This change in morphology marks the dividing line between the migrating or "live" dunes to the north and the stabilized dunes on the south. Figure 1-A16 shows the distribution of these dunes.

The linear aspect of the northern dune belt is almost certainly due to growth by accretion. Dune migration rates in this area have been measured as 12 feet per year (Fisher, 1972). Migrating dunes in the vicinity of Great Pond are presently burying a beech forest as they slowly move south. Dunes of the inner (southerly) portion of the hook were stabilized by plant cover as the hook grew larger, increasing the distance of these dunes from the exposed northern coast.

The history of the dunes just north of the residential section of Provincetown illustrates both the impact man can have on the delicate balance of nature and the very definite hazard presented by migrating dunes. This effect is described in greater detail in the next section, Cultural Erosion. In brief, practices employed by early settlers on the Cape denuded many acres of the

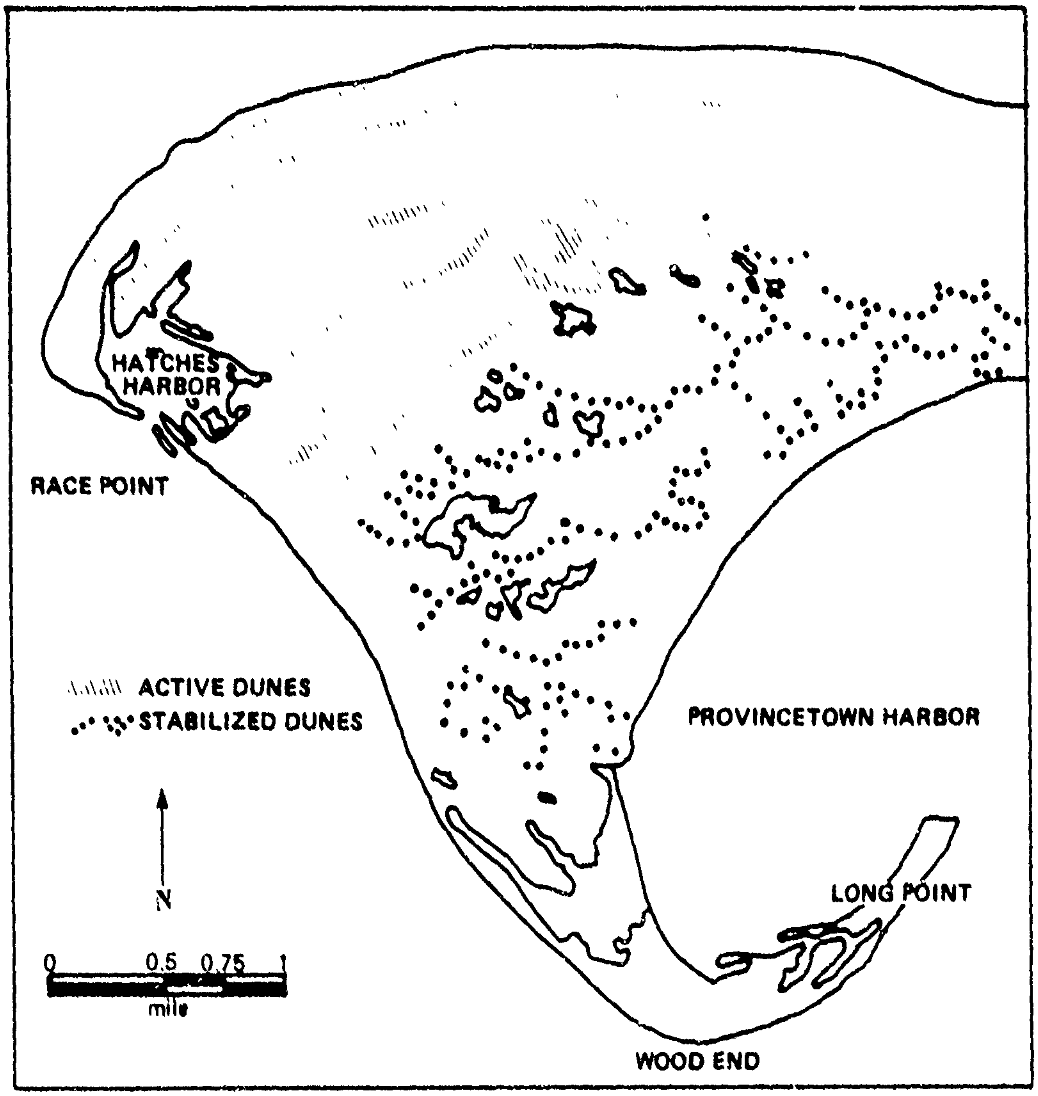

Figure 1-A16. Dune morphology (after Smith & Messinger, 1959)

Provinceland dunes within 100 years. With removal of the stabilizing plant cover, the dunes became subject to the erosional force of the wind, and serious dune migration occurred. It was not until the early 19th century that planting programs were instituted to stabilize the dunes. These programs and others have been successful on the southern dunes but the outermost northerly dunes are still migrating.

CULTURAL EROSION

Introduction

As described briefly in the previous section, cultural or accelerated erosion and landscape modification brought on by the activities of man have had a significant effect on Cape Cod. Denudation, erosion, and eventual restabilization of the dunes in the vicinity of Provincetown illustrate that man has both the capacity to harm the environment and the ability to correct many of his mistakes.

Early History

Archeological excavation near Assawompset Pond in Middleboro shows that ancient man lived in the area about 2300 B.C. Although his impact is not recorded, it probably was slight, and the damage (if any) inflicted by these early men was minimal and very temporary. Indians who settled on Cape Cod prior to 480 B.C. made the first significant ecological impact on the Cape. Several tribes such as the Pamet Indians of Truro, the Nausets in Eastham, and Monomojicks of Chatham lived on the Cape apparently in harmony with each other and certainly in harmony with nature. These Indians fished, hunted, and farmed, but their numbers were so small (estimated to be between 1,500 and 2,000 in 1620) and their needs so simple that these activities could be carried on without seriously upsetting the natural balance of the area. Periodically, tracts of land were cleared for new farms and larger areas were burned clear of underbrush in order to improve the hunting. The scope of their subsistence-level efforts at fishing, hunting, and farming and their lack of technology effectively prevented the Indians from inflicting much permanent change on the ecosystems of the Cape. With the possible exception of the burning of large tracts of land, any impact by the Indian was temporary and quickly healed by natural processes.

Impact of Modern Man

Pilgrims

When the pilgrims landed on the Cape, the land appeared as it had for hundreds of years prior to their arrival. It was thickly wooded with an abundance of fresh water and good soil. The coming of European man signaled the end of this abundance. Early settlers cleared woodlands for farms, cut timber, and developed industries. The agricultural system used in the 17th and early 18th centuries has been described as "vicious." Soils were fertilized only with fish and crabs and quickly became overcropped, leached, and progressively more barren; the land was overgrazed. Great tracts of land which had borne heavy forest cover became stripped of vegetation, and several areas turned into bare dunes.

Eolian erosion commenced. The prevailing wind direction was from the northwest, and sand began to migrate over the town and into Provincetown Harbor in large quantities. Early warnings by some legislators were commonly ignored, and wood cutting and pasture foraging continued until the effects of this cultural erosion began to be felt seriously. By 1725 it was too late for any immediate short-term solution. Valuable soil was blown away, houses in the town were threatened, streets were covered with sand, and thousands of tons of it had to be removed each year. Man fought a losing battle to keep the sand back. At the beginning of the 19th century the dunes were migrating toward the town harbor at rates of up to 90 feet per year (Chamberlain, 1964).

Some far-sighted individuals promoted conservation legislation as early as the early 18th century, but public awareness was slow in coming. The story of man's effect on dune migration in the Provincelands was repeated in varying detail all over the Cape. Common sense eventually prevailed, and practices such as overgrazing and overcutting ceased.

Between 1810 and 1830 a program of planting beach grass and pitch pine to stabilize the dunes was instituted. Laws prohibiting trespassing on the fragile dune tops were passed, and wood cutting was done only in certain areas with permission of town authorities. The indiscriminate grazing of animals was also stopped. The natural migration of sand, however, was difficult to control.

The conservation program was working, although slowly. A report of the area around 1875 reveals that an estimated million tons of sand a year was still moving south from the northerly dunes, but the southern dunes had finally become stabilized. The situation remains so today. The forest cover on the reestablished dunes is protected by law, and, hopefully, Provincetown will not be endangered again by the drifting sand. The outermost northerly dunes are still migrating, and most probably a program of sand removal (such as along Route 6 near Mount Ararat) will have to be continued to keep the populated areas free from drifting sand.

Current Cultural Erosion

Cultural erosion still exists on the Cape. Although different from that appearing in earlier times, its effect is still the same: an increased rate of erosion. Man is currently accelerating the erosion of the whole Cape and its beaches by excavation, traffic (both vehicular and foot), and various forms of shoreline construction. With rare exceptions, the outer beaches of the Cape are free from all forms of cultural erosion except vehicular and foot traffic. The dunes, barrier beaches (Nauset and Monomoy spits), and exposed scarps are noticeably affected by this kind of erosion. The traffic disturbs the vegetation which anchors the sand and stabilizes the dunes and scarps. A secondary effect is the disturbance of the surface layers of exposed sand. Once either of these situations occurs, the sand deposits in the area are much more susceptible to erosion.

Sand is anchored, either in dunes or other stabilized areas, primarily by beach grasses. These grasses are extremely adaptable to the beach-dune environment and, if left alone, will create a thick mass of roots that holds the sand very well. Beach grasses are very susceptible, however, to physical impact and thus are severely damaged by traffic. On grass-covered dunes or other sand deposits, once the plant cover is disturbed, the exposed loose sand is subjected to wind erosion. The bare spot will commonly grow as a blowout develops. In some cases, the careless damaging of only a small area of vegetation could contribute to the migration or erosion of a large mass of sand.

Of the entire area covered by this report, the beaches and dunes of the Provincelands are most affected by vehicular traffic. Further south (near Eastham), a system of established roads mitigates the problem of vehicular traffic. Foot traffic, however, causes a problem in all areas. Figure 1-A17 shows where foot traffic has worn paths into the dunes and cliffs at Marconi Beach.

The National Park Service (NPS) controls the beaches of the Cape Cod National Seashore which comprises most of the outer beach from Eastham to Provincetown. Access to the beaches is controlled by the size of parking lots, and the limitations are strictly observed. A system of permits and regulations regarding beach buggies and other recreational vehicles is maintained by the Service. Established dune trails are laid out to create the least possible impact on the area.

CONCLUSIONS

This section has attempted to show the fragile and impermanent nature of outer Cape Cod through an explanation and description of the geology of the Cape and the agents of erosion which are constantly at work. The forces of wind and water continually wear away, transport, and mold the unconsolidated sand, silt, and gravel of the Cape into new shapes and new forms. These forces will continue to modify and alter the shape of the land by working away at the beaches, bars, and cliffs that form the outline of the Cape.

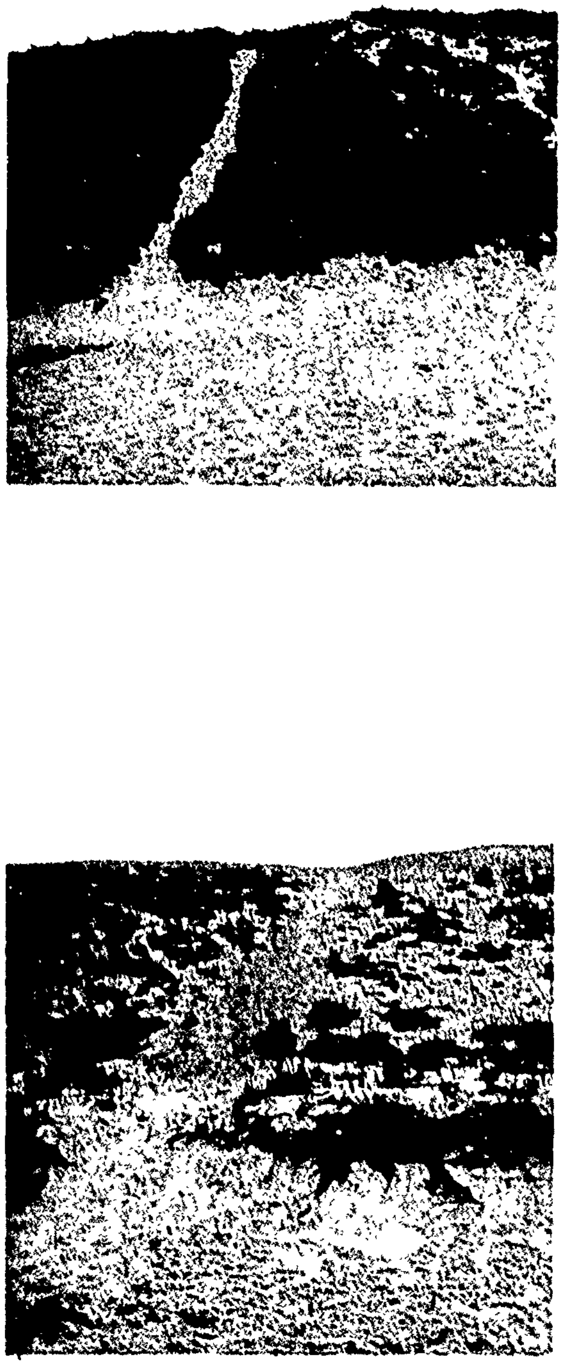

Figure 1-A-17. Effect of foot traffic on dune cover

Nauset and Monomoy beaches will probably elongate as the body of the Cape becomes narrower. The Provincelands will continue to extend outward to the sea, and at some time in the future the sea will break through the outer Cape. It cannot be determined exactly when or where the changes will occur. "New forms will be born of the old and will themselves generate change within the delicate balance of forces. A part of nature's continuum, it behooves us to live within it harmoniously." (Giese and Giese, 1974).

SECTION B

HYDROLOGY

HYDROLOGY

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ACKNOWLEDGMENT

Special thanks are extended to Dr. D. Lee Harris, Ph.D., of the Coastal Engineering Research Center, U.S. Army Corps of Engineers, for his suggestions relative to the organization of this chapter and for his technical input and informal review which have served to make this a more complete and accurate document.

INTRODUCTION

Wind generated waves are the principal agent of coastal erosion. Near-shore currents generated by waves, winds, astronomical tides or riverine flow also play an essential role. The precise location of most active erosion is determined to a significant extent by the water level as averaged over many wave periods. Along the eastern shore of Cape Cod and northward to the Bay of Fundy, the major variations in water level are produced by astronomical tides. Storm surges, due to high winds and variable atmospheric pressure, also produce significant variations in water level. Along the south shore of Cape Cod and westward, astronomical tides are the most persistent cause of water level variability, but the largest changes in water level are due to storms.

At times, atmospheric phenomena play a more direct role in changing the face of a beach. Wind can carry sand to or from the dunes. Rain, percolating through the soil, can reduce its stability and, at times, induce mud slides. Alternate freezing and thawing of the soil with changes in air temperature can also increase the erodibility of the soil.

The hydrodynamic factors responsible for erosion and sediment transport are examined in this chapter. Since many of these are related to the weather, a discussion of weather and climate is essential. This discussion of weather and climate is extended beyond the minimum requirements for a study of erosion to provide other background information needed for an evaluation of coastal projects.

Astronomical tides are discussed first for they are nearly independent of the other factors to be considered. Meteorological characteristics of the region are also nearly independent of the other phenomena to be considered; however, the net effect of meteorological forces on the water is measurably influenced by the tides. Therefore the initial discussion of tides is followed by a brief review of local weather characteristics, and this is followed by a brief review of notable past storms and regional climatology.

A trend toward rising sea level is clearly evident in this region. The rate of rise is too small to be important in considering changes within one or two seasons, but it must be recognized in interpreting the historical record or in making long-term predictions. The secular changes in sea level are considered in the last section of this chapter.

ASTRONOMOICAL TIDES

The Reason For Tides

The waters of the earth are free to respond to the gravitational attraction of the sun and moon somewhat independently from the response of the solid earth. Each particle of the earth is attracted toward the centers of the earth, moon and sun by a force which is proportional to the mass of the body and inversely proportional to the square of the distance to the center of the body.

The solid earth responds as though all of the force were applied at the center of the earth. Fluid particles, which are free to move, respond as though the force were applied at the center of each particle. The attractive force of the earth is directed along the vertical and is much stronger than the attractive force of the moon or sun near the surface of the earth. Thus the vertical component of the gravity fields of the sun and moon does not have any effect on the fluid motions of the earth. When the sun and moon are not immediately overhead, the attractive forces due to these bodies have components parallel to the surface of the earth that are not opposed by the gravitational attraction of the earth. These components of the gravitational fields of the sun and moon produce an acceleration of the fluid particles toward the subsolar and sublunar points and similar points on the opposite side of the earth.

The tide-generating force applied to any particle of the earth is the difference between the gravitational attraction of the sun or moon for that particle and the attraction of the sun or moon for the center of the earth. Since a difference is involved, the tide-generation force is inversely proportional to the cube of the distance between the bodies. As a result, the moon which is much smaller than the sun but much nearer the earth has a larger tide-generating force than the sun even though its gravitational force on the earth is less than one percent of that due to the sun.

At times of new moon and full moon the lunar and solar attractive forces are acting in the same direction. This position is called syzygy, (pronounced siz-a-gee) and during this condition high water rises higher and low water falls lower so that the range of the tide is greater than average. Such tides are called spring tides, and the range is the spring range. When the moon is in its first and last quarters, the tidal forces of sun and moon oppose each other and the tide does not rise as high nor fall as low as the average. Such tides are called neap tides, and their range is called the neap range. (See Figure 1-B1.) A cycle of one spring tide and one neap tide is about 14-3/4 days in length. There is a time lag between the moon's phase and the tidal response, which varies in different localities; at Boston Harbor the tidal extremes lag about 38 hours behind the lunar phases.

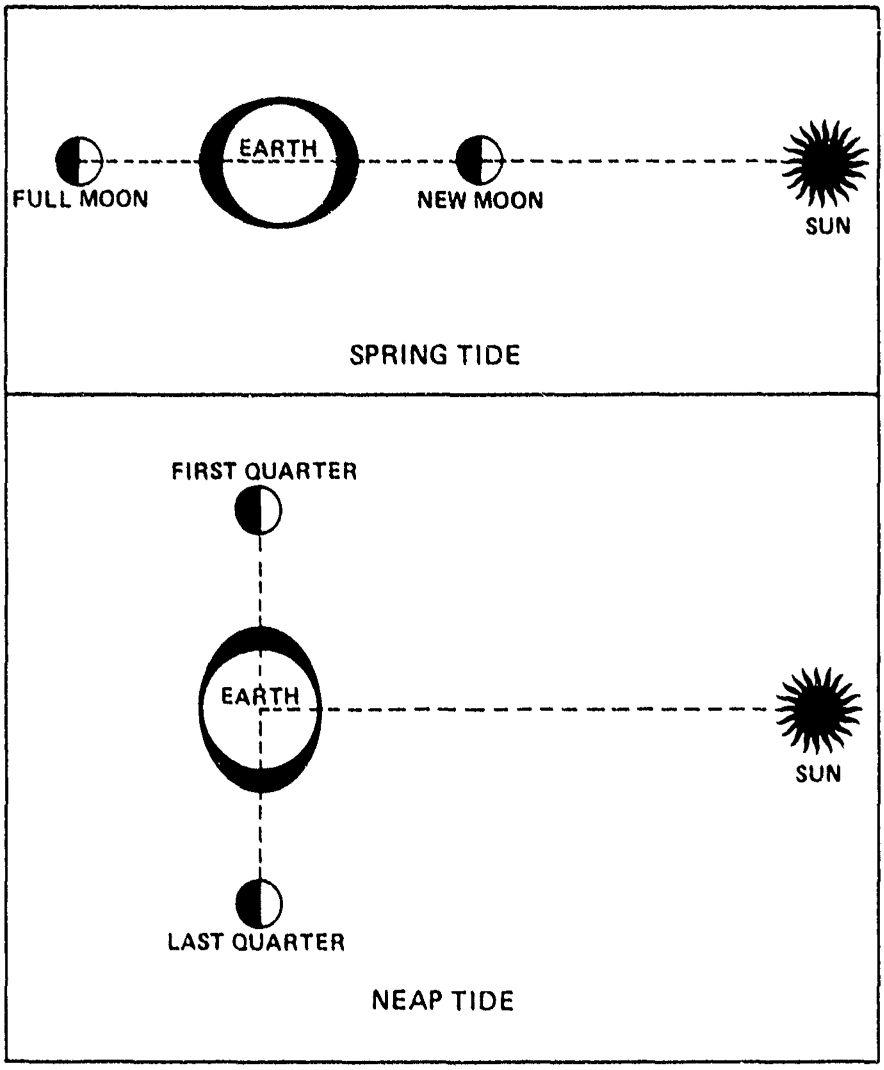


Figure 1-B1. Lunar and solar tidal effects

The varying distance from the earth likewise affects the range of the tide. In its movement around the earth the moon describes an ellipse in a period of approximately 27-1/2 days. When the moon is in perigee, or nearest the earth, its tide-producing power is increased, resulting in an increased rise and fall of the tide. These tides are known as perigean tides, and the range is the perigean range. There is a time lag between lunar perigee and maximum tidal effect of about 58 hours at Boston Harbor. If the occurrence of spring tide is coincident with the maximum tidal response to lunar perigee, the combined perigean spring tide results in an even greater tidal range.

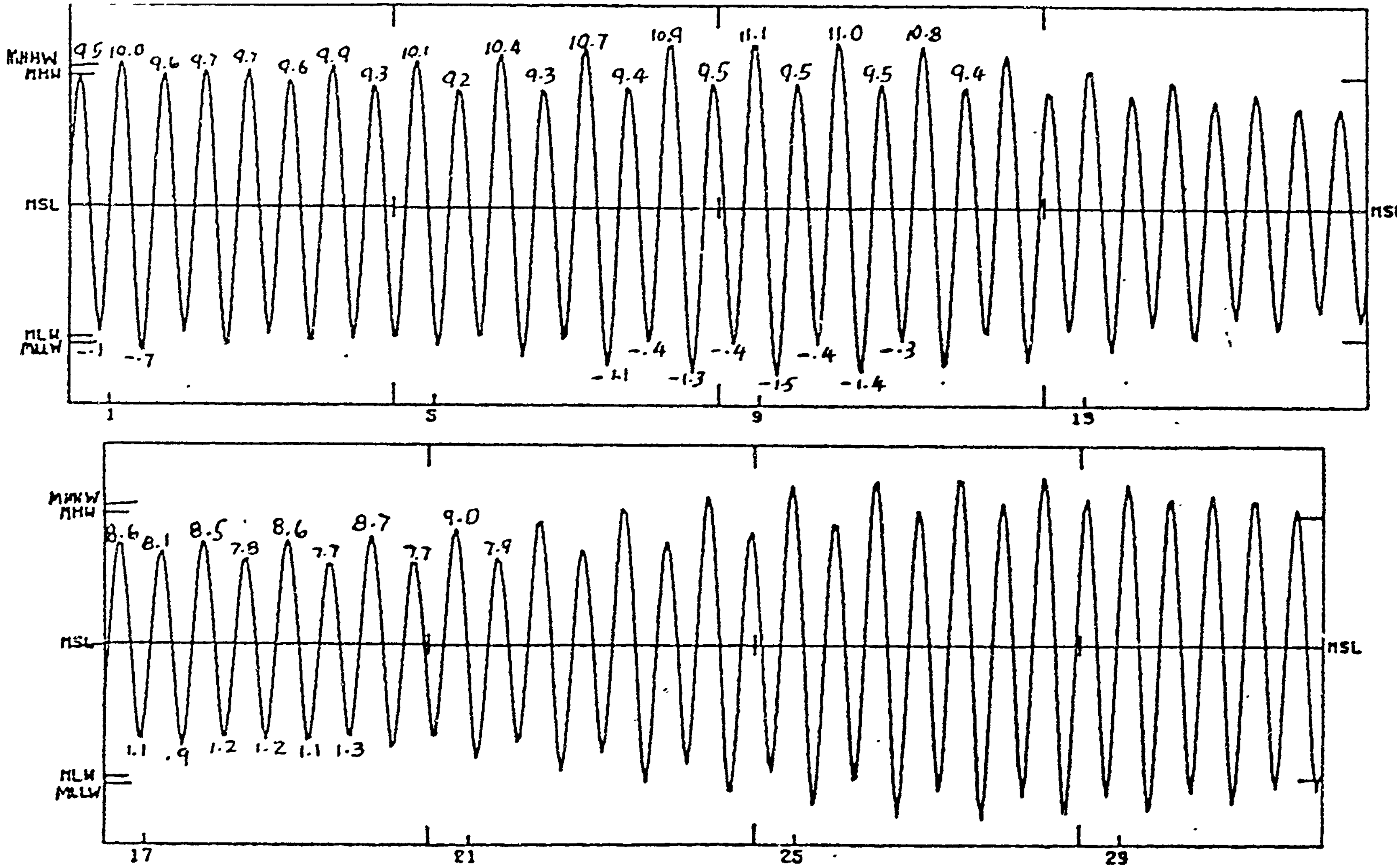
When the moon's orbit is on or close to the equator (that is, when the declination is small), consecutive ranges do not differ much; morning and afternoon tides are very much alike (equatorial tides). As the declination increases, the difference between consecutive ranges increases and morning and afternoon tides begin to show decided differences to the times of the moon's maximum semi-monthly declination (tropic tides), these differences are very nearly at a maximum. A complete cycle of equatorial and tropic tides takes approximately 27-1/3 days.

It is seen that the amplitude of the tide is modulated by several phenomena which have periods of the order of 28 to 30 days. The maximum tide ranges occur when two or more of these phenomena are nearly in phase. A complete sequence of tide ranges is approximately repeated at intervals of 19 years, which are referred to as metonic cycles. Consequently a period of 19 years of observation is preferred for the establishment of tidal datum planes such as mean low water (MLW) and mean sea level (MSL). Wood (1978) has summarized a large volume of data which shows that the variability in tide range has a great effect on tidal flooding. He recommends that more attention be paid to the extreme ranges of astronomical tides.

Sample Hydrograph Of Astronomical Tides

A hydrograph of the predicted astronomical tide in Boston Harbor for January 1963 is shown in Figure 1-B2. The variations in water level shown in this figure are reasonably typical of most Atlantic coast locations in the United States. A few high and low water elevations, referred to local mean low water have been entered above or below the curve to provide perspective for the day to day changes in tide range in response to the phenomena discussed above. The hydrograph indicates that the high tide elevation varied from 3.1 feet to 6.5 feet above the local mean sea level and the low tide varied from 3.3 feet to 6.1 feet below the local mean sea level. It can also be seen that the maximum range for the month, 12.6 feet, was nearly double the minimum range, 6.4 feet. The variation in the astronomical tide range over a period of several years can be even greater. The high water at Boston may be as little as 2.4 or as much as 7.3 feet above the

Figure 1-B2. Tidal height curves for Boston, Massachusetts



HOURLY TIDE HEIGHTS

BOSTON, MASS JANUARY, 1963 M.R. - 9.68 FT 2.95 M

A few representative tide heights, referred to local mean low water appear on the graph.

local mean sea level and the low tide as little as 2.6 feet or as much as 7.4 feet below local mean sea level. The National Ocean Survey (NOS) bases tide predictions for Cape Cod on detailed calculations for Boston Harbor. The range of tide from mean low water to mean high water at most locations on the Cape, especially west of Chatham, is less than that at Boston. (See Table 1-B1.) Estimated maximum and minimum tide ranges for various locations on the outer Cape have been computed by adjusting the values for Boston by the ratio of the mean tide range at the location of interest to the mean tide range in Boston Harbor. These are also shown in the table.

Tidal Datum Planes

Because of the continual variation in water level due to the tides, several reference planes, called tidal datums, have been defined to serve as a reference zero for measuring elevations. The most fundamental of these is Mean Sea Level, abbreviated as MSL. Mean sea level is defined as the arithmetic mean of hourly water elevations observed over a specific 19-year metonic cycle (the National Tidal Datum Epoch). The epoch currently in use for mean sea level determination in the United States is 1941-59. Sea level is rising with respect to the land along most of the U.S. coast. Therefore the sea level determination is revised at intervals of about 25 years.

Mean sea level is defined only for explicit locations where suitable tide records are available. A reference level which can be used as a zero in elevation measurements even where no tide records are available is needed for mapping and many other applications. This reference is provided by the National Geodetic Vertical Datum of 1929 (NGVD). This datum was established by overland geodetic surveys with the intention of having the Geodetic Vertical Datum coincide with local mean sea level at 25 U.S. and Canadian tide stations. Geodetic surveys from the coasts have been used to carry this datum to a network of bench marks covering the United States. Because of land subsidence and rising sea levels, the NGVD is, today, lower than the MSL most everywhere in the United States. At Boston, the National Ocean Survey's present official mean sea level, based on tide gage records, is about 0.15 ft NGVD.

A third tidal datum, widely used by coastal engineers along the Atlantic coast, is mean low water (MLW). Mean low water is defined as the arithmetric mean of low water heights observed over a specific 19-year metonic cycle (the National Tidal Datum Epoch). Like mean sea level, mean low water is properly defined only for specific tide gage locations. Mean low water is a useful datum for hydrographic surveys where it is the minimum water depths that are most critical for navigation. Unfortunately MLW is often used for land surveys in the coastal region where MSL or MGVD would be more appropriate.

Table 1-B1. Astronomic tide ranges for Boston and Outer Cape Cod

Location	Mean Tide Range (feet)	Mean Spring Tide Range (feet)	Estimated Maximum Tide Range (feet)	Estimated Minimum Tide Range (feet)
Boston	9.5	11.0	14.7*	5.0*
Provincetown	9.0	10.6	14.1	4.8
Race Point	9.0	10.4	13.9	4.7
Cape Cod Light	7.6	8.8	11.8	4.0
Nauset Harbor	6.0	7.0	9.3	3.2
Chatham (Outer Coast)	6.7	7.8	10.4	3.5
Chatham (Inside)	3.6	4.2	5.6	1.9
Pleasant Bay	3.2	3.7	5.0	1.7
Monomoy Point	3.7	4.3	5.7	1.9

Mean and mean spring tide range data obtained from the "Tide Tables 1978, High and Low Water Predicitions" by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Survey.

*Actual value, based upon 19 year Metonic tide cycle. Taken from forthcoming CERC publication entitled "Tides and Tidal Patterns for U.S. Waters," due to be published late in 1979.

METEOROLOGICICAL FACTORS

Storm Types

Two distinct types of storms, known as extratropical and tropical cyclones, which can produce above normal water levels, must be recognized in studying coastal problems in New England.

a. Extratropical Cyclones

The most frequently occurring type of cyclone in New England is the extratropical variety. Low pressure centers frequently form or intesify on the polar front just off the coast of Georgia or the Carolinas and move northeastward more or less parallel to the coast. The low pressure center often passes a short distance southeast of Cape Cod. With this type of storm track, the highest wind speeds over New England are generally from the northeast. For this reason, these storms are often called "nor'easters" in this region, even though the storm centers are generally moving from the south or the southwest. The local wind direction over the Cape may vary from east to slightly west of north. Winds from this quadrant are directed toward the shore and are generally accompanied by high waves and above normal water levels.

The nor'easter forms along the boundary between a continental air mass, generally one which has recently been in equilibrium with the cold dry planes of Western Canada, and a marine air mass which has spent several days over the warm moist Atlantic Ocean. The energy of the extratropical cyclone is derived from the temperature contrast between the cold and warm air masses. As a result of the thermal difference between these air masses, the marine air mass, generally southeast of the polar front, rides up over the colder air mass to the northwest. The moist air mass is cooled by the reduction of pressure and condenses, forming rain or snow. The latent heat of condensation acts to further warm the air and increases the thermal gradient across the front. The polar front is called a warm front in any region in which the warm air is advancing along the ground, and a cold front where the cold air is advancing. The minimum pressure generally occurs at the junction of the cold and warm fronts. This juncture of the cold and warm air masses may be compared to the crest of a wave on the water. The wave travels through the water at a much greater speed than any water particles. The low pressure center in the nor'easter can, likewise, travel along the polar front with a greater speed than any of the winds in the system. The wind speed and storm speed in this type of storm are not closely related. The organized circulation pattern associated with this type of storm may extend for 1000 to 1500 miles from the storm center. The wind field in an extratropical cyclone is generally asymmetric with the highest winds in the north or northeastern quadrant. These win blowing from northeast. north or northwest, while the storm center is moving toward the northeast.

No reasonably simple and usefully accurate method of describing the wind field in an extratropical cyclone is known. Interpolation or extrapolation from available observation is generally satisfactory provided one considers data from only one air mass. That is, the interpolation or extrapolation must not cross a front.

b. Tropical Cyclones

Tropical cyclones form in a warm moist air mass over a tropical ocean. The air mass is nearly uniform in all directions from the storm center; surface winds spiral inward from all directions. The air rises in a ring near the storm center. In the actual center, the air often descends, producing a cloud free eye. The temperature of the rising air is lowered because of the reduced pressure. Condensation occurs because of the decreased temperature. This supplies the latent heat of condensation to the air and intensifies the vertical motion, thus drawing more surface air into the storm. The energy for the storm is provided by the latent heat of condensation. The tropical cyclone has a much simpler structure than the extratropical type. When the maximum wind speed in a tropical cyclone exceeds 75 MPH (64 knots), it is called a hurricane. Although the hurricane structure is actually quite complex, it is useful for many purposes to think of the hurricane as a circularly symmetric vortex imbedded in a flowing stream. When considered in this manner, the wind velocity at any position can be estimated as the sum of a rotating windfield in which the velocity depends only on the distance from the center and a uniform current which carries the storm along. It should be recognized this estimate is only an approximation to a more complex reality. The maximum wind speeds in a hurricane may occur less than 10 miles from the storm center and rarely more than 30 miles from the center. The organized wind field may not extend more than 300 to 500 miles from the storm center. Because of the small size of tropical cyclones and the low density of weather observations over the sea during stormy conditions, the surface wind field is never recorded in much detail and the method of estiamting the wind velocity just described is generally more accurate than interpolation between available observations. This is in sharp contrast to conditions in extratropical cyclones.

Generation Of Waves By The Wind

When a steady wind starts to blow over a calm body of water, waves are developed. The wave height and period increases with the wind speed, the duration of the wind and the distance (fetch) over which the wind blows. The exact details of the process are not yet fully identified, but the foregoing statements are universally accepted. The wave height and period may ultimately reach a maximum with duration or fetch of the wind. This question has not been thoroughly settled, but it is not critical here because the durations available in the Cape Cod area are not great enough to permit

equilibrium to develop during storm conditions. The maintenance of wave gages near the coasts during storms is difficult, and it is nearly always necessary to use estiamtes of wave conditions based on the available meteorological data (wave "hindcasts") to obtain a substantial part of the wave estimates needed in planning engineering activity in the coastal zone. Figure 1-B3 shows the frequency of occurrence of various wave heights from different directions as estimated by one of the early wave hindcasting procedures. This figure provides a summary of one of the best available estimates. of wave climate for the Cape Cod region. Both the quantity and quality of the meteorological data available for wave hindcasting have been improved since 1950. The processes of wave generation are much better understood now than in 1954 when these estimates were made. A revision of the data presented in this figure should become available sometime in 1979.

EFFECTS OF STORMS ON WATER LEVELS

Three distinct processes may produce an increased water level near the coast during storms.

The Inverted Barometer Effect

In the deep sea, a reduction in atmospheric pressure is accompanied by a rise in the sea surface which will lead toward a constant pressure level at some distance below the water surface. Although for equilibrium to be achieved the water would have to rise about 13-25 inches for a pressure drop of one inch of mercury, the approximation of a one-foot rise in water level for a one-inch fall in atmospheric pressure is often used. Nearshore boundary conditions at the bottom or sides may alter the response of the sea to pressure changes so that the actual rise is generally less than that indicated above, but it can be greater. This tendency for the water level to rise under low atmospheric pressure is often called the "inverted barometer effect."

Wind Setup

Friction between the wind and the water surface generates a current, which is initially parallel with the wind, but which, because of the rotation of the earth, rotates toward the right with increasing time and increasing depth so that the water transport due to a steady wind on very deep water

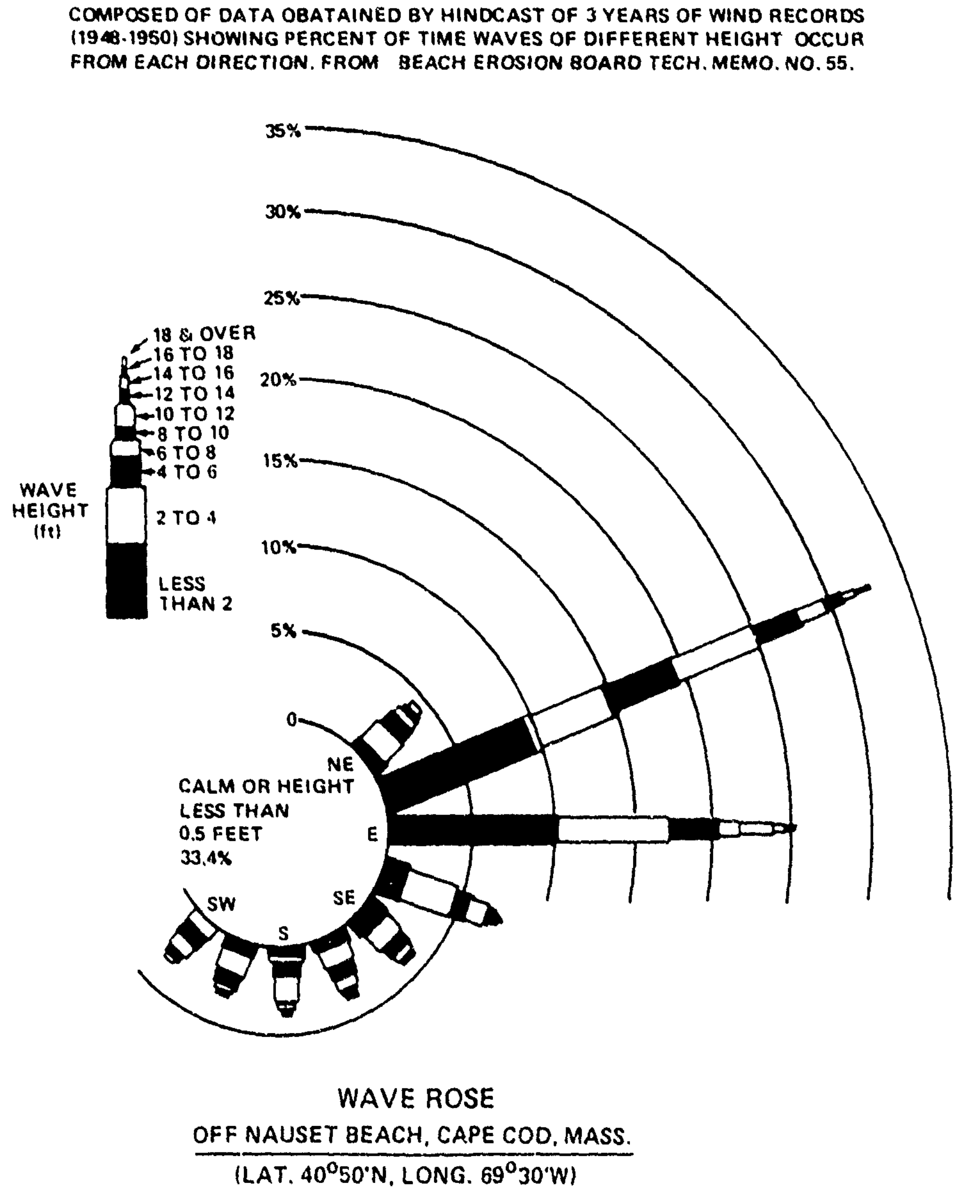


Figure 1-B3. Wave rose

is about 90° to the right of the wind. In shallow water, far from the shore, the direction of the current differs little from the direction of the wind. Near the shore the current is constrained to flow parallel to the shore but, because of the earth's rotation, the mean free surface slopes upward to the right of the wind. Thus both the component of the wind that is directed on shore and the component that is parallel to the shore, with the shore to the right, tends to produce above normal water level. The direct effect wind setup, is inversely proportional to the water depth. Thus the effect of a given wind velocity is greater at low tide than at high tide and is limited to shallow waters near the shore. The wind effect is approximately proportional to the square of the wind speed.

Wave Setup

The mean water velocity due to periodic waves vanishes beneath the wave trough. Between the wave trough and the wave crest, however, there is always a net flow in the direction of wave propagation. The magnitude of this flow is proportional to the square of the wave height. Thus the mean current due to the waves increases more or less continuously from deep water to the breaker zone, thus producing a downward slope of the mean water surface from the region in which the bottom begins to affect the waves to the breaker zone. The wave amplitude must vanish in the region between the breakers and the water line, producing an upward slope of the water surface called the wave setup. The wave setup is often steeper than the wind setup, but it is restricted to a much more narrow region near the shore.

The wave setup is usually correlated with the wind setup because high wind and high waves are often correlated. However the process of wave generation extends much further seaward than the effective wind setup. Waves can travel as swell far from their region of generation. Thus wave setup can occur in the absence of wind or even with an adverse wind.

The combined affects of winds, atmospheric pressure and wave setup are often called the storm surge. The contribution due to wave setup is often neglected.

COMBINED EFFECTS OF ASTRONOMICAL TIDES AND STORM SURGE ON WATER LEVEL

A Case Study

A sample water level record showing the combined effects of astronomical tides and storm surge is shown in Figure 1-B4 taken from Pore (1973). A plot of the hourly observed tide heights for the storm period, February 17-21, 1972, for the North Atlantic coast of the U.S. is shown. Figure 1-B5 is a plot of the storm surge, defined as the difference between the observed and the astronomical tides. It can be seen from these figures that the tide range is much greater along New England's east coast than along its south coast, but the contribution of the storm surge to the total water level was generally higher along the south shore than at Boston and other east shore tide gages. It is presumed that the surge values along the eastern shore of Cape Cod are higher than those in Boston, but no tide gage records are available for evaluating this concept.

The peak storm surge occurred near noon on 19 February near the lower high tide of the day. The maximum water level would have been nearly a foot higher if the surge peak had occurred about 12 hours earlier near the highest astronomical tide of the month.

Summary Of Extreme High Tides At Boston

Systematic tide observations, with few interruptions, have been made in Boston at Commonwealth Pier No. 5 since 1921, and the tide records since then are relatively complete and reliable. Monthly high tide levels were recorded from 1847 to 1876 and from 1903 to 1911 at the Boston Navy Yard. There are few interruptions in these records, and they are considered quite reliable. The record for earlier years is spotty and not as reliable as the record for later years. Nevertheless, some extremely high tides for earlier years have been described in newspaper accounts or elsewhere, and it would be short-sighted to neglect this informal data altogether. Forty of the highest tides recorded in Boston are tabulated in Table 1-B2. These heights are all referenced to NGVD of 1929. The highest predicted astronomic tide for the day of the recorded storm high tide and the difference between this value and the recorded value are shown for all reported values after 1940. This difference represents the lower bound of the storm surge component. When examined in this manner, it appears that the largest storm effect is about 3.5 feet, during the storm of 7 February 1978, with a maximum water level of 10.4 feet. If this 3.5-foot surge had occurred during the highest of predicted high tides during the 19-year metonic cycle, the combined water level would have been at least 11.0 feet NGVD. Conversely, if it had occurred during the lowest of predicted tides, the level could have

SOURCE: Monthly Weather Review, Vol. 101, No. 4, April 1973

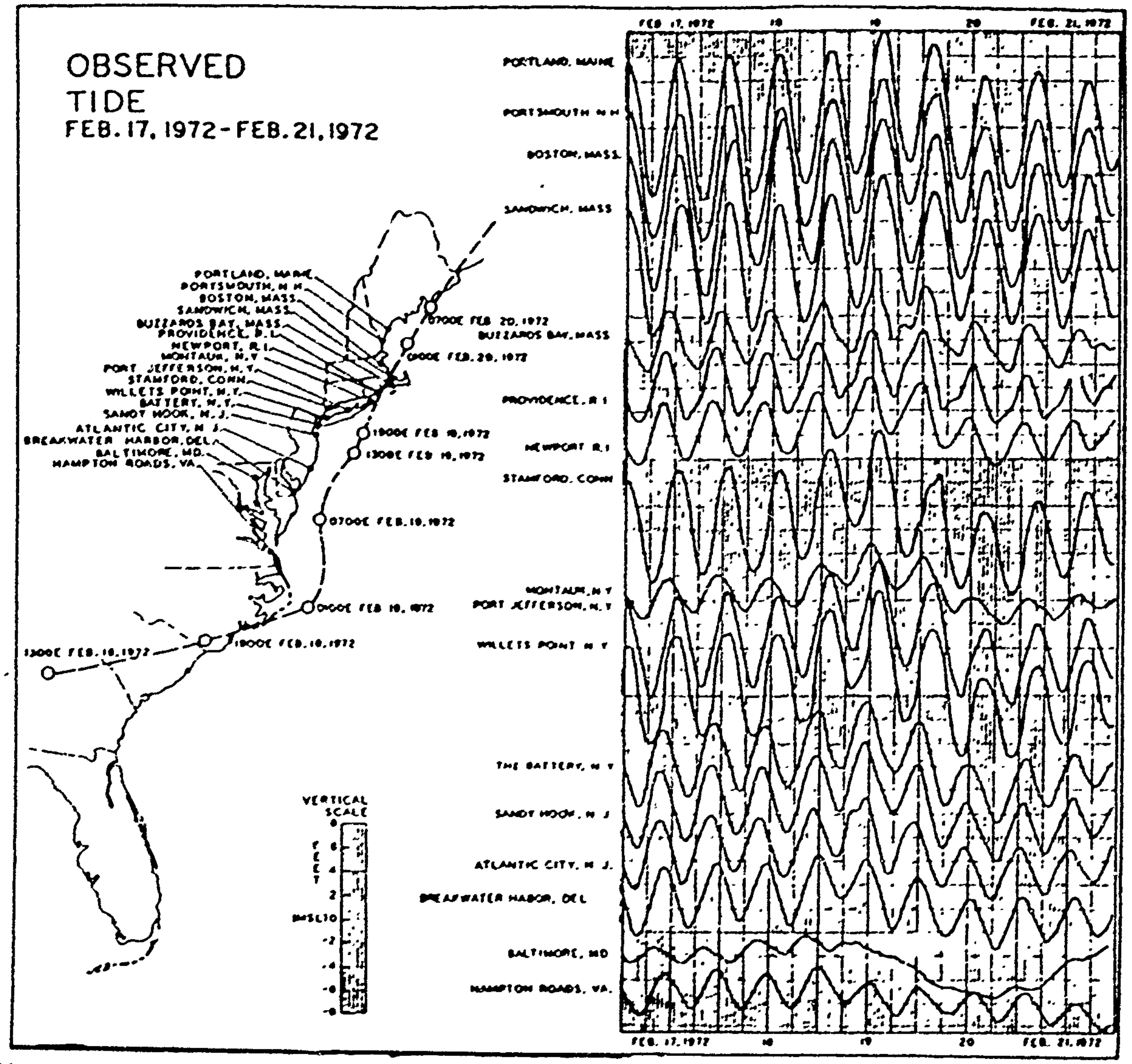


Figure 1-B4. Six-hourly positions of the storm center and observed tide as recorded by tide gages of the National Ocean Survey. (The date for each day is placed at the 1200 EST position.)

SOURCE: Monthly Weather Review, Vol. 101, No. 4, April 1973

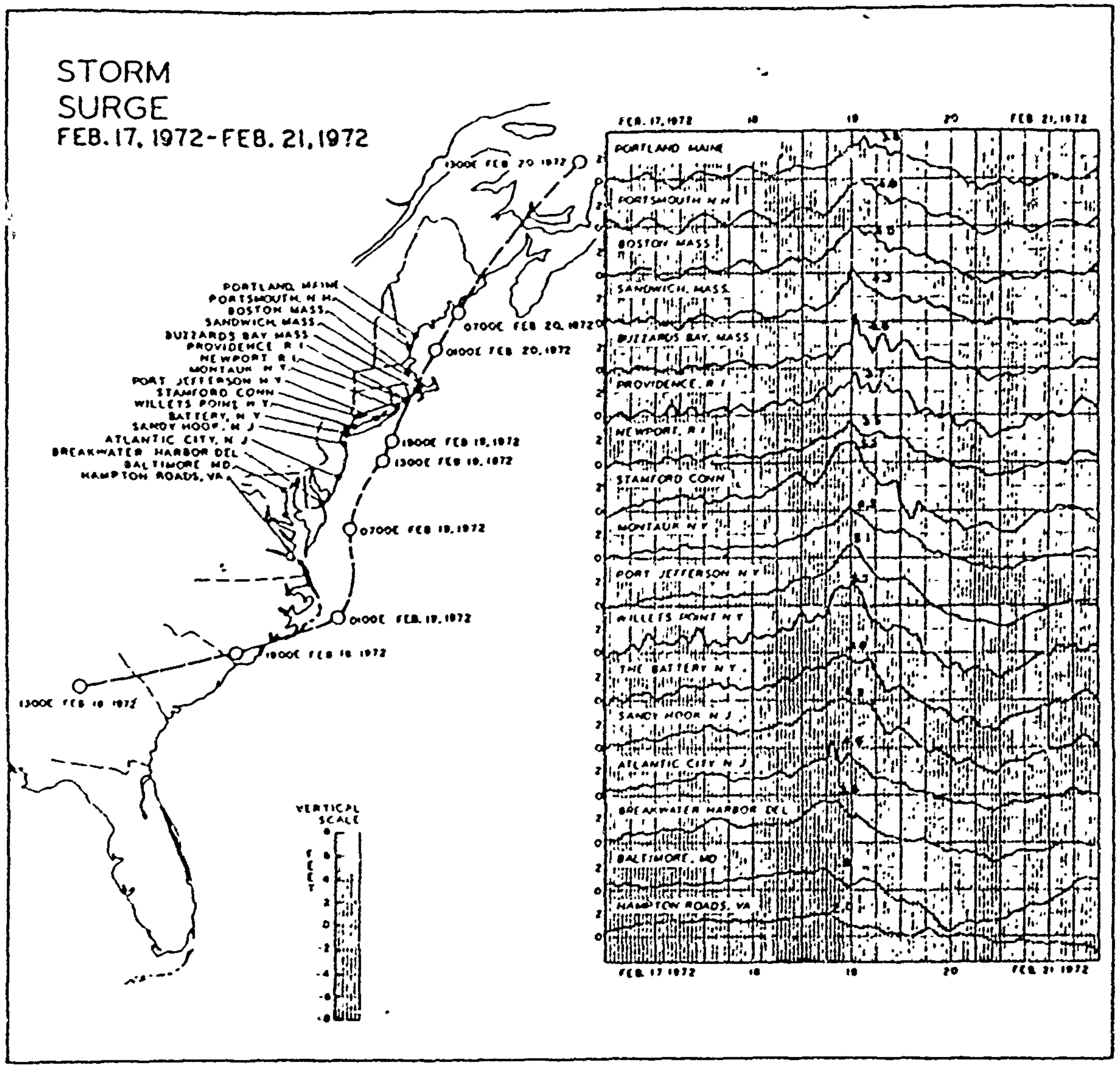


Figure 1-B5. Six-hourly positions of the storm center and the storm surge (observed tide minus the normal astronomical tide.) The maximum value (ft) is indicated on each curve and the date for each day of record is placed at the 1200 EST position.

Table 1-B2. Maximum tide heights, Boston, Massachusetts

(HEIGHTS IN FEET)

Date	Reported Elevation (NGVD)[3]	Predicted High Tide of the Day (NGVD)	Difference[2]	Predicted Highest Tide of Month (NGVD)	Adjusted Elevation[1] (NGVD)
7 Feb 1978	10.4	6.9	3.5	7.0	10.3
16 Apr 1851	10.1				11.0
26 Dec 1909	10.0				10.6
27 Nov 1898	9.4				10.1
29 Dec 1959	9.3	7.3	2.0	7.5	9.4
15 Dec 1839	9.2				10.2
27 Dec 1839	9.2				10.2
24 Feb 1723	9.1				10.7
19 Feb 1972	9.1	6.3	2.8	6.3	9.1
26 Mar 1830	9.0				10.0
29 Dec 1853	8.9				9.8
4 Dec 1786	8.9				10.2
21 Apr 1940	8.9	7.1	1.8	7.2	9.2
26 May 1967	8.9	6.7	2.2	6.9	8.9
3 Dec 1854	8.8				9.7
4 Mar 1931	8.8				9.2
30 Nov 1944	8.8	6.9	1.9	7.1	9.1
20 Jan 1961	8.8	6.6	2.2	7.3	8.9
3 Nov 1861	8.7				9.6
17 Mar 1956	8.6	5.9	2.7	6.3	8.7
23 Nov 1858	8.5				9.4
15 Nov 1871	8.5				9.3
7 Apr 1958	8.5	7.0	1.5	7.3	8.6
7 Mar 1962	8.4	7.1	1.3	7.1	8.5
2 Dec 1974	8.4	6.5	1.9	6.8	8.4
31 Dec 1857	8.3				9.2
28 Jan 1933	8.3				8.7
4 Apr 1973	8.3	6.6	1.7	6.7	8.3
22 Dec 1972	8.3	6.9	1.4	7.1	8.3
6 Jan 1856	8.2				9.1

(Table continued on next page)

Table 1-B2 (Continued)

(HEIGHTS IN FEET)

Date	Reported Elevation (NGVD)[3]	Predicted High Tide of the Day (NGVD)	Difference[2]	Predicted Highest Tide of Month (NGVD)	Adjusted Elevation[1] (NGVD)
12 Nov 1947	8.2	6.1	2.1	6.6	8.4
28 Feb 1952	8.2	6.2	2.0	6.8	8.4
31 Aug 1954	8.2	5.3	2.9	6.2	8.4
2 Nov 1963	8.2	7.2	1.0	7.2	8.3
7 Feb 1974	8.2	7.0	1.2	7.0	8.2
11 Dec 1952	8.1				9.0
19 Jan 1855	8.1				9.0
7 Mar 1864	8.1				9.0
9 Jan 1868	8.1				8.9
13 Apr 1953	8.1	7.0	1.1	7.0	8.3

[1]Reported values after adjustment for rising sea level; adjustment made to 1970 sea level conditions. See the section entitled, "Rising Sea Level."

[2]The storm surge must be equal to or slightly higher than the value in this column.

[3]NGVD means "National Geodetic Vertical Datum of 1929."

been as low as 6.1 feet NGVD. The highest predicted tide of the month is also tabulated to the right of the difference column for comparison. It is seen that the extremely high tides in Boston result from a combination of extremely high astronomical tides with storm surges and that the contribution of about normal astromonical high tides is about as significant as storm effects in determining the peak water levels. An estimated effect of the contribution of the rising sea level is shown in the final column of this table.

NOTABLE STORMS

Introduction

The shores of Cape Cod are vulnerable to the erosive action of wind-driven seas associated with major storms. When examining the effects of storms on the Cape Cod coastline, one immediately recognizes that the phenomenon responsible for coastal flooding is not the same along its entire coast. The orientation of the coastline determines what storms have the most significant impact. For areas west of Chatham Harbor, the principal causes of flooding are the tropical storms (hurricanes) that push up ocean levels against the exposed southerly facing land mass. On the other hand, the easterly facing coastline from Chatham to Provincetown is vulnerable to the storm surges generated by extratropical storms (northeasters) moving along the coast. Storm tide-surges resulting from wind and wave setup and barometric effects can be especially disastrous when coincident with high spring tides. Huge and furious waves, sometimes reaching heights of 20 feet or more, break on the offshore bars. Beach sand is cut away and transported by the turbulent surf to other locations along the shore or to deeper water. Cliff walls are undermined and slough into the rough seas. The height of the beach can be reduced by as much as 10 feet in a single spot when a high tide brings the storm surf on to the beach (Giese and Giese, 1974). A dramatic example of the extent of the degradation - aggradation process is the fact that, as recently as 1844, flood tides occasionally crossed Cape Cod at Orleans (Conference on Coastal Meteorology, 1976) but no longer do because of subsequent filling of the low area by transported sediments.

Northeasters

a. General

Coastal storms in New England, commonly referred to as northeasters, have been recorded in the history of the region from the time of the first settlers. Over a 75-year period the Weather Bureau at Boston reported 160 gales (storms with continuous winds over 32 miles per hour,) and half

of these blew from the northeast (U.S.Weather Bureau, 1963). Table 1-B3 provides a breakdown of the predominant wind directions of these gales.

Table 1-B3. Direction of gale winds at Boston (75-year period)

DIRECTION[1]	N	NE	E	SE	S	SW	W	NW	TOTAL
NUMBER	3	80	9	14	12	15	13	14	160
PERCENT OF TOTAL	2	50	6	9	7	9	8	9	100

[1]Variations in direction during the gales are not accounted for.

Most of the region's memorable storms are northeasters, resulting from coastal low pressure systems passing either near or over Cape Cod and adjacent waters. The more destructive of these storms have occurred between November and April. By tradition it has become commonplace to refer to any coastal storm (except a hurricane) along the middle Atlantic and New England states with strong onshore winds as a northeaster. This definition will be used throughout this report.

Northeasters that produce strong winds along the New England coast are well-developed and mature, extra tropical, low-pressure systems. Storm surges of 2 feet or more due to northeasters occur at Boston about five times per year; surges of 3 feet or more are almost an annual occurrence (U.S. Department of the Interior, 1974). When high winds occur in coincidence with extreme astronomic high tides, very destructive coastal water levels are experienced. Many of the more notable surge-producing storms have been associated with a high-pressure area located ahead of the storm acting to block its forward motion. The blocking phenomenon tends to create an unusually long fetch in the forward semicircle of the storm, documented at greater than 1500 miles on two occasions. Fetch lengths of 600 miles or less are more commonly observed.

The basic regions where cyclones either first appear or develop over North America are Alberta, Canada, and the Pacific Coast, Colorado, Central, Texas-East Gulf and South Atlantic regions of the U.S. (See Figure 1-B6.) Of the 51 surge-producing northeasters analyzed in a study by the Hydrometeorological Section of the U.S. Weather Bureau (1963), 73 percent developed in the Texas-East Gulf and South Atlantic regions. These storms were grouped according to wind direction at the coast shortly before peak surge, and the mean tracks of the groups were plotted (Figure 1-B7). It was noted that the onshore winds shifted from SE to E to NE as the storm tracked farther offshore.

Maximum occurrences of development of low pressure systems in the Texas-East Gulf and South Atlantic regions take place during the colder months when the temperature contrast between maritime and continental air masses along the southern coast is greatest. Lows from these areas often develop rather quickly and intensify into severe storms over the mid-Atlantic and

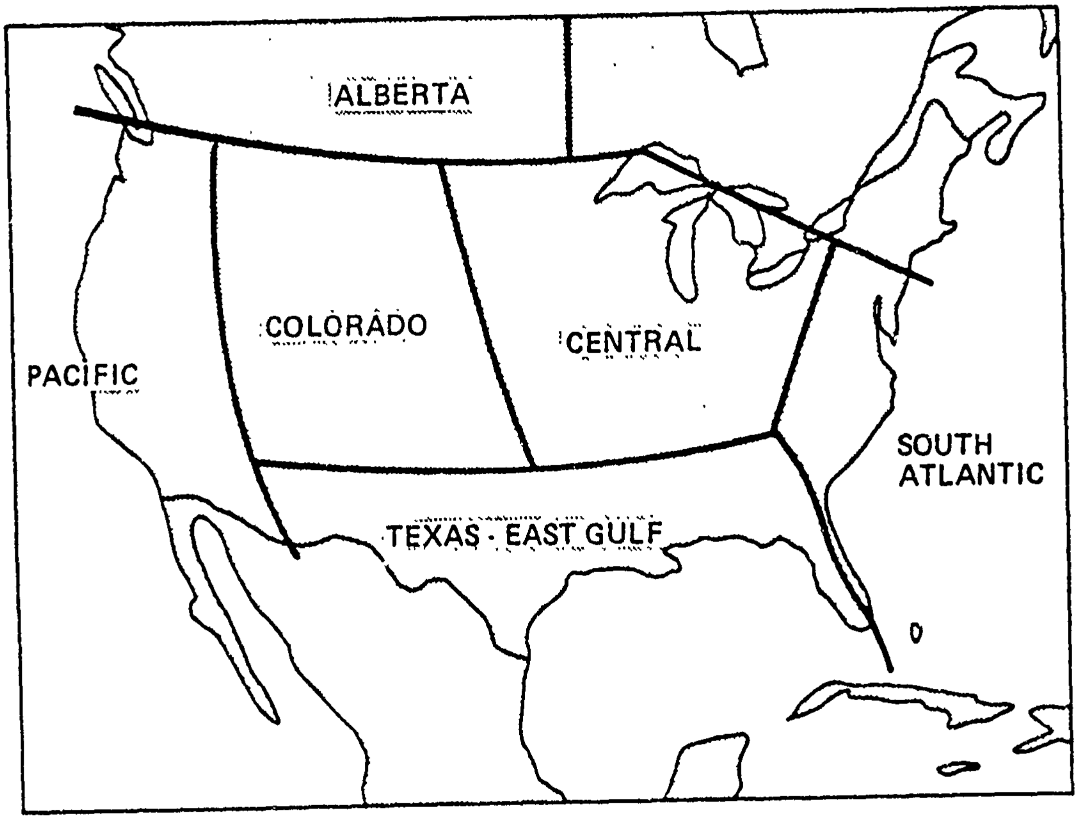


Figure 1-B6. Regions of extra-tropical cyclonic development

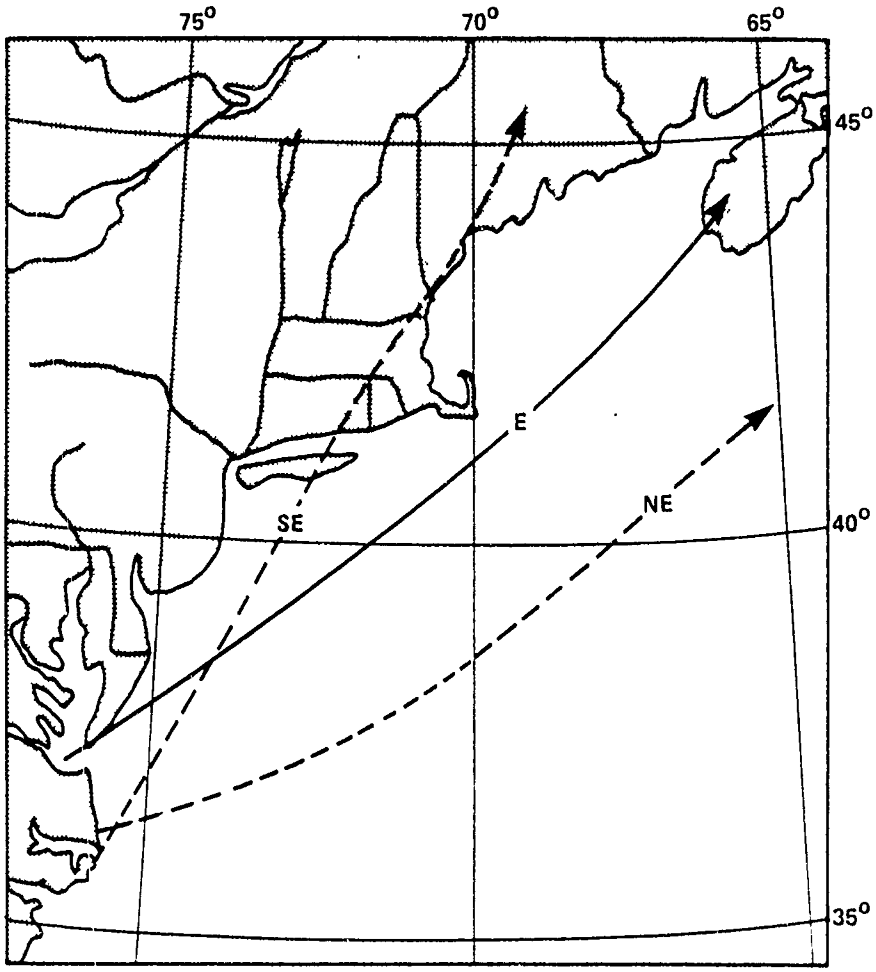


Figure 1-B7. Mean tracks of surge-producing northeasters

New England states. The average speed of advance of the 51 storms studied was 25 miles per hour, ranging from nearly stationary to a maximum speed of 49 miles per hour. Wind speeds are frequently on the order of 50 to 60 miles per hour, with gusts occasionally approaching 100 miles per hour.

b. History

Table 1-B3 summarizes the number of gales (continuous winds with velocities in excess of 32 miles per hour) recorded by the U.S. Weather Bureau in Boston, Massachusetts, for the 75-year period 1870-1945. Storms generating winds from the northeast predominate, constituting 50 percent of the total.

The mean monthly number of northeasters that influenced New England weather during a 50-year period is shown in Table 1-B4. (Geographically, northeasters that influence New England weather are taken here to be those passing through the 5-degree latitude-longitude square in the quadrant northeast of 40°N-70°W; refer to Figure 1-B7.)

Table 1.B4. Mean monthly number of northeasters

MONTH	NUMBER OF EVENTS
November	3.0
December	4.4
January	3.8
February	4.3
March	3.7

Descriptive comments on the most recent northeasters affecting the Cape Cod area, as well as some of the major storms for which historical records exist, are as follows:

6-7 February 1978. While areas were still in the process of recovering from the effects of the 20 January 1978 blizzard, New England was struck by one of the most intense, persistent, severe winter storms of record. The storm moved slowly eastward just south of New England as a circular upper atmospheric low moved over the surface circulation. It produced intensely strong winds - gusts of 92 miles per hour were recorded at Chatham on outer Cape Cod and 79 miles per hour at Boston - and great amounts of snow over most of New England - 40 inches fell at one location in southeastern Massachusetts.

The persistent winds, coupled with a perigean spring tide that happened to occur during the peak of the 18.6-year Metonic tide cycle, developed one of the highest tides of record along the coast from Chatham, Massachusetts, to Eastport, Maine. The greatest tides of record were measured at the N.O.S. gages at Boston, (Table 1-B2) Portsmouth and Portland on the morning of February 7th. The high tides and hard-hitting waves brought great destruction to the easterly exposed coasts of Massachusetts, New Hampshire and Maine. Damages to public facilities such as sea walls, piers

and harbors in these three states totaled over 17 million dollars while loss or damage of 11,500 private homes along the Massachusetts coast alone amounted to an estimated $172,000,000. The general economic loss due to the storm was estimated at over $400,000,000 in Massachusetts.

9 January 1978. A freak winter storm characterized by balmy weather, drenching rain and hurricane winds battered much of New England. The storm was the result of a deep low pressure area that moved through western New York early on the morning of January 9. The low pulled the warm air off the ocean causing the torrential downpour and the strong southeasterly gales. Wind gusts of 60 to 75 miles per hour were reported along the entire New England coast. The storm surge coincided with the astronomic spring tide causing extremely high tides along the Maine coast north of Portland. In Portland, the tide produced by this event was the greatest since systematic observations of tide levels began in 1912. Provincetown was also severely hit; flood damages caused by the storm's southeasterly winds reached one million dollars. (Southeast winds hit hard on the exposed northern flank of Cape Cod Bay.) Tides 2 to 5 feet above normal were reported elsewhere along the New England coast.

Damage attributed to the storm consisted of hundreds of roofs blown off, extensive inland flooding, coastal homes suffering severe structural damage, widespread beach erosion and scores of personal injuries.

2 February 1976. Hurricane-force winds gusting to 92 miles per hour at Nantucket and 98 miles per hour at Chatham accompanied this intense storm which formed in Georgia and moved northward at speeds up to 60 miles per hour. It caused the second lowest pressure ever recorded at Boston (28.48 inches) Tides ran about 3 feet higher than normal along the Cape, with many boats sinking or blowing ashore.

2 December 1974. A severe coastal storm produced 12-foot waves and northeast winds gusting to 50 miles per hour. Tides ran approximately 2 feet above normal.

19 February 1972. A deep low pressure area moving at about 25 miles per hour over outer Cape Cod produced storm surges of 4.0 feet at Boston and 4.3 feet at Sandwich, superimposed on the coincident spring tides. Damage was inflicted on thousands of homes and shore buildings along coastal sections of Maine, New Hampshire and Massachusetts, which were declared an official disaster area. Many sandy beaches were left a mass of boulders, and large sections of roads and sidewalks were washed away. At Coast Guard Beach in Eastham it was estimated that 15 to 20 feet of beach eroded away. The Race Point Coast Guard Station observed winds gusting to 100 miles per hour. Waves overtopped Monomoy Island and North Beach (The Cape Codder, 1972).

26 May 1967. A particularly severe northeaster that was especially late in the season, it was comparable in effect to the nearby passage of a full hurricane. The storm's movement was slowed due to a blocking high pressure ridge, and coincident spring tides combined with gale force winds to

cause extensive beach erosion. The Race Point Coast Guard Station observed 8- to 10-foot waves from the morning of the 25th through the afternoon of the 26th. Over 6 inches of rain fell at Nantucket in a 24-hour period.

20 January 1961. A blizzard that originated off the Oregon-Washington coast produced very high storm tides along Cape Cod, reaching 4.5 feet above normal at Nantucket. Several popular beach areas were eroded by the storm action. Highway flooding occurred in Brewster, Dennis and Wellfleet, with winds gusting to 60 miles per hour.

29 December 1959. Easterly gales from a storm center at sea pushed water 2.5 feet higher than one of the normally highest spring tides of the year. Boston recorded a tide of 9.3 feet above MGVD. the highest since the 1909 "Christmas Gale".

Provincetown experienced a tide of approximately 9.0 feet above NGVD with hip-deep water in the East End (The Provincetown Advocate, 1959). The winds, although not unusually strong, persisted in a direction normal to the New England shore from Cape Cod to Portland, Maine, during the period of the incoming tide. This wind pattern prevailed over the whole area of the ocean north of the stationary front, resulting in a fetch of over 300 miles. The two major damage sectors on Cape Cod were at Provincetown, with some 65 residential and 20 commercial properties affected, and at Barnstable with 13 residences affected. Damages were attributed to wave action, flooding or both. U.S. Routes 6 and 6A were flooded in several areas along the north shore of the Cape. Additional damages consisted of erosion to shore front and highway embankments throughout the area.

Winter of 1958. About 18 storms, mainly northeasters, occurred during the winter and spring. Observed tides were as much as 2 to 4 feet above normal spring tide levels, causing flooding in many communities along the New England coastline from Connecticut through Maine. Maximum sustained wind velocities varied from 35 to 60 miles per hour, with gusts up to approximately 70 miles per hour, causing heavy wave damage. Very severe shoreline erosion, estimated at approximately 35 feet in width, but reaching 50 feet in some places, was reported from Provincetown to Monomoy Island.

26 December 1909. The "Christmas Gale" produced the third highest tide, 10.0 feet NGVD, in over 250 years of unofficial record at Boston (see Table 1-B2), while Provincetown experienced its highest observed tide of 9.8 feet above NGVD. The following historic account provides a vivid description:

> At Boston Light the predicted time of high tide was 10:20 a.m. The wind from the late afternoon of the 25th until nearly noon of the 26th, was from the east and northeast over Boston Harbor and Massachusetts Bay, rapidly increasing in force during the evening of the 25th to very high velocities soon after midnight, which continued undiminished through the morning and day of the 26th. At Cape Cod, Highland Light, the wind velocity at 8 a.m.

> of the 26th was 48 miles northeast; noon 72 miles; 2:15 p.m. 84 miles; at 5 p.m. 66 miles all from the east-northeast and at midnight was 60 miles north. (Monthly Weather Review, 1910)

These are uncorrected wind values (not adjusted for instrumental error). Corrected values are about three-fourths of the values given.

14 April 1851. The "Lighthouse Storm", so named for the loss of the Minot's Ledge Lighthouse at Cohasset, was a severe rain, hail and snow storm that resulted in the second highest tide recorded at Boston, 10.1 feet above NGVD, which at the time was the highest tide measured in Boston. (According to historical accounts, one storm, the 15 August 1653 hurricane, resulted in higher water levels, but sufficiently reliable data is not extant.) Widespread losses of life and property were experienced in all New England coastal areas, but especially those exposed to the northeast winds.

> On all parts of the coast where the northeast wind could exert its force the tide rose over the wharves from one to four feet. At Provincetown, on Cape Cod, many wharves and salt mills were swept away; and in several places people left their houses, which were flooded, water being six inches deep on the lower floors in some of them. (Perley, 1891).

26 April 1718. Little is known about this storm, but one historical account of its effect on Wellfleet is striking: "The winds were so strong and the waves were so great and powerful that the sea forced its way across the Cape, which was very narrow at this place (near Wellfleet), creating a channel so large that a whaleboat passed through it at the time." (Perley, 1891).

Hurricanes

a. General

The southern coast of New England, including the outer Islands and the south shore of Cape Cod, has experienced or has been threatened by hurricane tidal flooding on 72 known occasions during the period from 1635 to date. That portion of the Atlantic coastline running in a generally north-south direction has been affected more severely and far more often by northeast storms than by hurricanes. However, hurricanes do have a significant adverse affect on the immediate shorelines, producing high winds and surge tides which cause serious coastal damages. Of the 72 recorded hurricanes that hit or narrowly missed southern New England, 13 caused severe coastal flooding, 25 caused damage from wind and rain and were usually accompanied by high seas and moderate coastal flooding, and 34 posed threats to the area. The lack of records and information

on storms prior to 1900 suggests that probably significantly more hurricanes posed threats, but were not recognized as such.

b. History

The tracks of the major recent hurricanes are shown in Figure 1-B8. Some storms, such as "Diane" in August 1955, are remembered most for the torrential rains, up to 20 inches, which caused extreme flooding in southern New England. The 21 September 1938 "Great New England Hurricane" caused devastating wind damage as it advanced at a rate of 50 to 60 miles per hour up the Connecticut River valley. A brief description follows of those notable hurricanes that most affected the Cape Cod area.

12-13 September 1960. Hurricane "Donna" weakened as it moved northward, with no sustained hurricane force winds experienced on mainland New England. Tides along shores with a southern exposure ran 5 to 6 feet above normal, but coastal regions subject to easterly influences, such as Boston and Portsmouth, New Hampshire, saw only 2- to 2-1/2-foot surges. Coastal flooding was only moderate as the time of the storm surge was coincident with a low astronomic high tide. Timely and accurate forecasts and warnings minimized loss of life and property.

31 August 1954. Hurricane "Carol" wreaked havoc on the south shore of New England, leaving 68 dead and $300,000,000 in property damages. Over 10,000 buildings and 3,000 small craft were destroyed or seriously damaged. The regions extending eastward from the path of the center experienced hurricane winds with gusts to 125 miles per hour. Vacationers in beach resort areas sustained most of the deaths and injuries as coastal regions were subject to storm-driven winds and water. At Woods Hole, tide elevations exceeded those of September 1938 but were about 1-1/2 feet less than September 1944. At Boston, "Carol's" surge tide exceeded both these events by more than 1 foot but was still lower than numerous recorded storm tides resulting from northeasters. Eleven days later "Edna" skirted the Cape Cod area with high winds and heavy rains, but damage was comparatively light.

14-15 September 1944. The "Great Atlantic Hurricane" struck New England at Point Judith, Rhode Island, and caused extensive damage in the Cape Cod area. Fatalities numbered 26 in the six-state region, with over 300 lost at sea. Winds at Chatham averaged in excess of 80 miles per hour in a south-southeasterly direction for over an hour and a half. A Geological Survey report (Chute, 1946) cited as much as 45 to 50 feet of cliff erosion at beaches from Woods Hole to Chatham. The tide along Nantucket Sound east of Falmouth was equivalent to that of a 100-year frequency event, due primarily to the coast's southern exposure. By comparison, tide levels in Boston were only a foot above mean high water. Even though it declined in strength before it reached New England, the Great Atlantic Hurricane was one of the most destructive storms ever to hit the south shore of Cape Cod.

3 October 1841. The "October Gale" was particularly severe on Nantucket and outer Cape Cod.

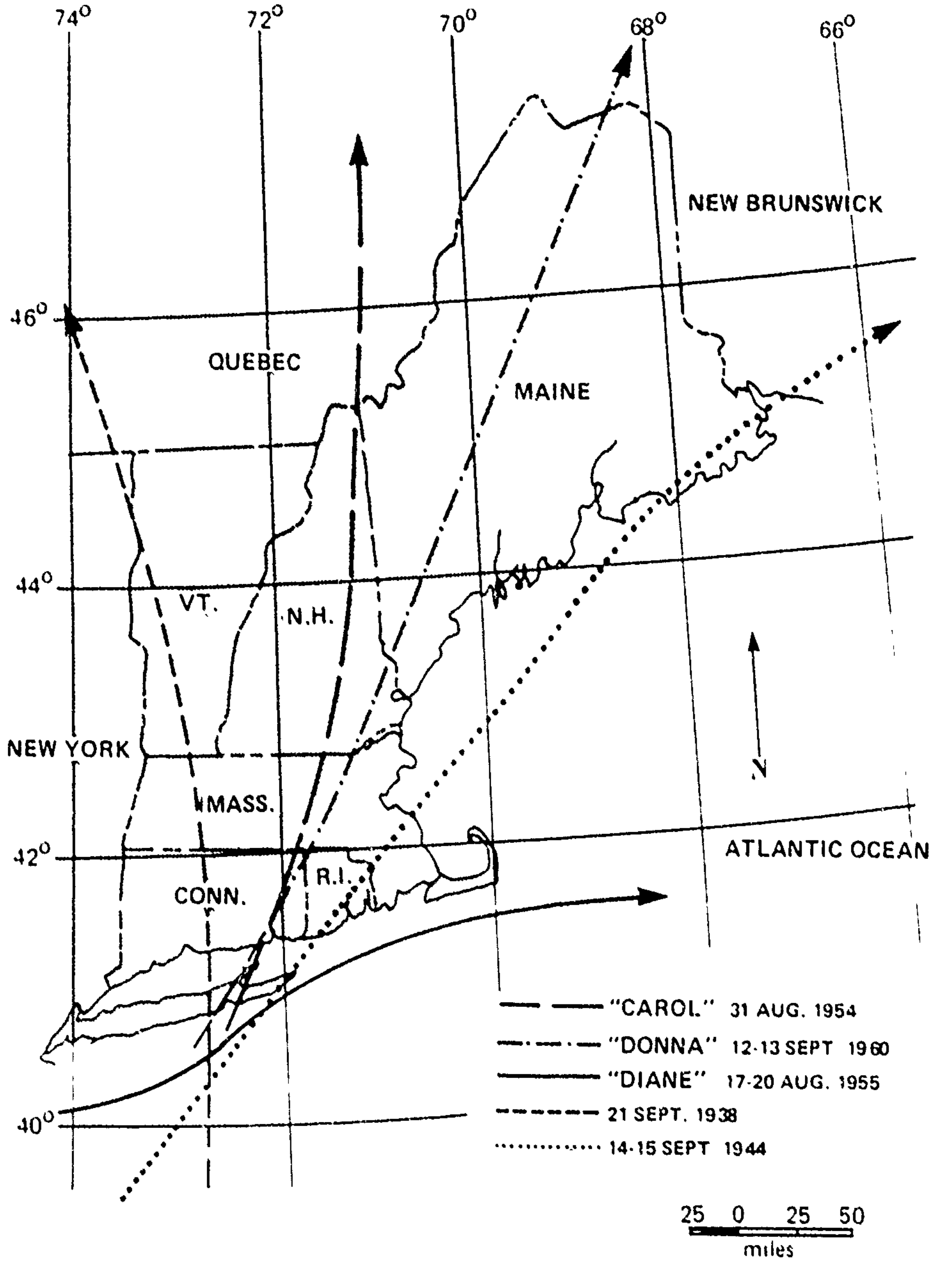


Figure 1-B8. Tracks of selected hurricanes

The beach from Chatham to the highlands was literally strewn with parts of wrecks. Between 40 and 50 vessels went ashore on the sands there, and 50 dead bodies were picked up...Most of the vessels of Truro were on or near the southwest part of Georges Banks, and on the night of the second, the crews left off fishing, and made sail to run for the highland of Cape Cod. Mighty ocean currents that they had never encountered before carried them out of their course to the southwest, but being disabled by the gale they were driven upon the Nantucket shoals, which extend 50 or 60 miles into the ocean. Fifty-seven from Truro were lost and buried in the great ocean cemetery.(Perley, 1891)

15 August 1635. The "Great Colonial Hurricane" produced the highest known tides in many New England ports. William Bradford's observations, as recorded in his diary "Of Plymouth Plantation, 1620-1647" vividly describe the storm's fury:

It began in the morning, a little before day, and grew not by degrees, but came with violence in the beginning to the great amazement of many. It blew down sundry (211) houses, and uncovered others; divers vessels were lost at sea, and many more in danger. It caused the sea to swell (to the southward of this place) above 20 feet, right up and down, and made many of the Indians to climb into trees for their safety... It blew down many hundred thousands of trees, turning up the stronger by the roots, and breaking the higher pine trees off in the middle, and the tall young oaks and walnut trees of good bigness were wound like a withe, very strange and fearful to behold.

CLIMATOLOGY

General

The notable storms, discussed in the above section, are superimposed on a continuity of less extreme weather conditions. It is the collection of all weather conditions, means as well as extremes, which form the climate of a region. Climatic data for the Cape Cod region are reviewed in this section.

Moderate temperature and ample precipitation characterize the climate of Cape Cod. The average yearly precipitation at Provincetown is 38.7 inches, with an average annual temperature of approximately 49° Fahrenheit. Cape Cod Bay and the open Atlantic Ocean lying to the east effectively moderate both summer and winter temperatures. Winter cold waves, usually borne by northwesterly winds, are considerably tempered before reaching the Cape, though very cold temperatures occasionally occur. Much day-to-day variation is experienced due to the relatively frequent passage of weather

systems (Table 1-B4) that bring alternately warmer and cooler air to the region. Precipitation frequently accompanies these changes. The Cape's terrain is mostly flat rolling, with a few hills approaching elevations of 300 feet. While such terrain differences can influence minimum temperatures on calm nights, the range of elevation is too small to be an important weather controlling factor. Cape Cod is subject to the tropical and extra-tropical cyclonic distrubances that periodically affect the New England area. These are discussed in more detail in the section entitled "Notable Storms."

Temperature

Mean monthly temperatures recorded at Provincetown range from 30.2°F in February to 69.7°F in July. Nantucket experiences slightly more moderate temperatures, averaging 31.7°F in February and 68.0°F in July. The mean, maximum and minimum monthly and annual temperatures at Boston, Provincetown and Nantucket are summarized in Table 1-B5. Very hot weather is uncommon on Cape Cod, the 90°F mark generally being reached only about one year in two. Similarly, zero degree weather occurs in only about one winter in two, or even less. The record low temperatures for Provincetown and Nantucket are -6°F and -3°F, respectively, while the recorded highs are 104°F and 100°F.

Precipitation

Precipitation is distributed almost uniformly throughout the year, with slightly greater amounts occurring during the winter season. Seldom does less than 1.0 inch of precipitation occur in a month. Annual precipitation recorded at Provincetown has ranged from a minimum of 22.93 inches to a maximum of 58.20 inches; the extremes in Nantucket are a low of 25.31 and high of 60.39 inches. The average annual number of days when measurable amounts (0.01 inch or more) of precipitation occur at Provincetown is 118, decreasing to 110 at Hyannis (The Climate of Cape Cod, 1964). Showers and thunderstorms, often relatively brief, provide the heavier rains of the warm season. Only occasionally do hurricanes reach notable proportions. Coastal storms, or "northeasters", are prolific producers of rain and snow during the cool season. Monthly and annual precipitation for Boston, Provincetown and Nantucket are shown in Table 1-B6.

Table 1-B5. Air temperatures (degrees Fahrenheit) at stations near Cape Cod, Massachusetts (Records through 1975)

	BOSTON 104 YEARS			PROVINCETOWN 75 YEARS			NANTUCKET 30 YEARS		
MONTH	MEAN[1]	MAXIMUM[2]	MINIMUM[2]	MEAN[1]	MAXIMUM[2]	MINIMUM[2]	MEAN[1]	MAXIMUM[2]	MINIMUM[2]
January	29.1	72	-13	31.1	62	-4	32.1	57	3
February	19.3	68	-18	30.2	60	-3	31.7	56	0
March	37.6	86	-8	36.3	76	0	36.4	62	7
April	47.3	91	11	44.6	83	16	43.9	73	20
May	57.8	97	31	54.3	90	25	52.2	80	28
June	67.3	100	41	63.8	98	37	61.1	88	38
July	72.4	104	50	69.7	104	44	68.0	92	47
August	71.5	102	46	68.8	98	34	67.9	100	43
September	64.4	102	34	62.8	93	29	62.5	86	34
October	55.0	90	25	53.4	82	22	54.4	82	23
November	44.5	83	-2	44.1	77	14	45.8	74	18
December	32.9	69	-17	35.0	68	-6	36.3	60	-3
ANNUAL	50.8	104	-18	49.4	104	-6	49.4	100	-3

[1]Mean of the daily average air temperature for month indicated.

[2]Instantaneous value.

Table 1-B6. Monthly precipitation (inches) (Records through 1975)

	BOSTON 105 YEARS			PROVINCETOWN 82 YEARS			NANTUCKET 30 YEARS		
MONTH	MEAN[1]	MAXIMUM[2]	MINIMUM[2]	MEAN[1]	MAXIMUM[2]	MINIMUM[2]	MEAN[1]	MAXIMUM[2]	MINIMUM[2]
January	3.57	9.54	0.89	3.76	8.96	1.13	3.92	8.24	1.19
February	3.39	7.08	0.45	3.48	9.15	0.67	4.01	8.07	2.30
March	3.85	11.00	T*	3.72	7.56	T*	4.10	8.88	0.97
April	3.57	9.14	0.93	3.54	8.31	0.57	3.87	8.41	2.17
May	3.24	13.38	0.25	3.01	10.49	0.27	3.63	8.24	0.59
June	3.20	9.13	0.27	2.81	8.20	0.10	2.15	5.01	0.01
July	3.15	11.69	0.52	2.56	8.65	0.03	2.57	7.45	0.07
August	3.60	17.09	0.39	3.14	9.57	0.10	3.78	12.92	0.28
September	3.27	10.94	0.21	3.34	15.76	0.47	3.62	9.49	0.07
October	3.24	8.84	0.06	3.44	9.05	0.30	3.17	7.45	0.37
November	3.87	11.03	0.59	3.55	9.40	0.45	4.24	7.83	1.06
December	3.72	9.74	0.66	3.68	8.90	0.93	4.28	6.88	1.30
ANNUAL	41.67	67.72	23.71	39.74	58.20	22.93	43.35	60.39	25.31

*T denotes "trace" of precipitation.

Snowfall

The principal snowfall season is December through March, with an average annual occurrence of 7 to 8 days in which 1.0 inch or more accumulates. A 4-inch or greater snowfall can be expected to occur on the average of twice a year. Snow cover does not usually remain on the ground longer than about two weeks per year. The average seasonal maximum depth of snow on the ground is 9 to 10 inches, usually occurring in February, although the date can vary widely. Cape Cod receives much less snow than the rest of New England, reflecting the moderating effects of the ocean body on the winter climate.

Wind

The wind roses shown in Figures 1-B9 and 1-B10 provide a graphical representation of the frequency of wind speeds and directions based on hourly observations by the National Weather Service at Logan Airport at Boston and Memorial Airport at Nantucket, Massachusetts. Winds in excess of 32 miles per hour have a high frequency of occurrence in the northeast quadrant.

RISING SEA LEVEL

Sea level has been rising world wide at varying rates for thousands of years. Since the maximum advance of the last glacier at about 13,000 B.C., sea level has risen approximately 430 feet (Meade 19__). With retreat of the glacial ice, the phenomenon of "rebound" of the landmass has accounted for more than 600 feet of increased elevation in northern areas of New England where the ice sheet was very thick. Cape Cod is a glacial moraine that at one time formed the boundary of the ice sheet. Approximately 7,000 years ago Cape Cod and Martha's Vineyard and Nantucket Islands were all part of the same landmass that extended some 25 miles eastward from the present east coast of Nantucket. Part of the fishing shoal which is known as Georges Bank and lies 100 miles east of Cape Cod was then an island (Giese and Giese, 1974). The sea has been slowly reclaiming Cape Cod. The overall rate of cliff erosion has averaged about 2.6 feet per year in recent times, caused mainly by wave action. The mean height of the sea, with respect to the adjacent land, has been rising in the United States with

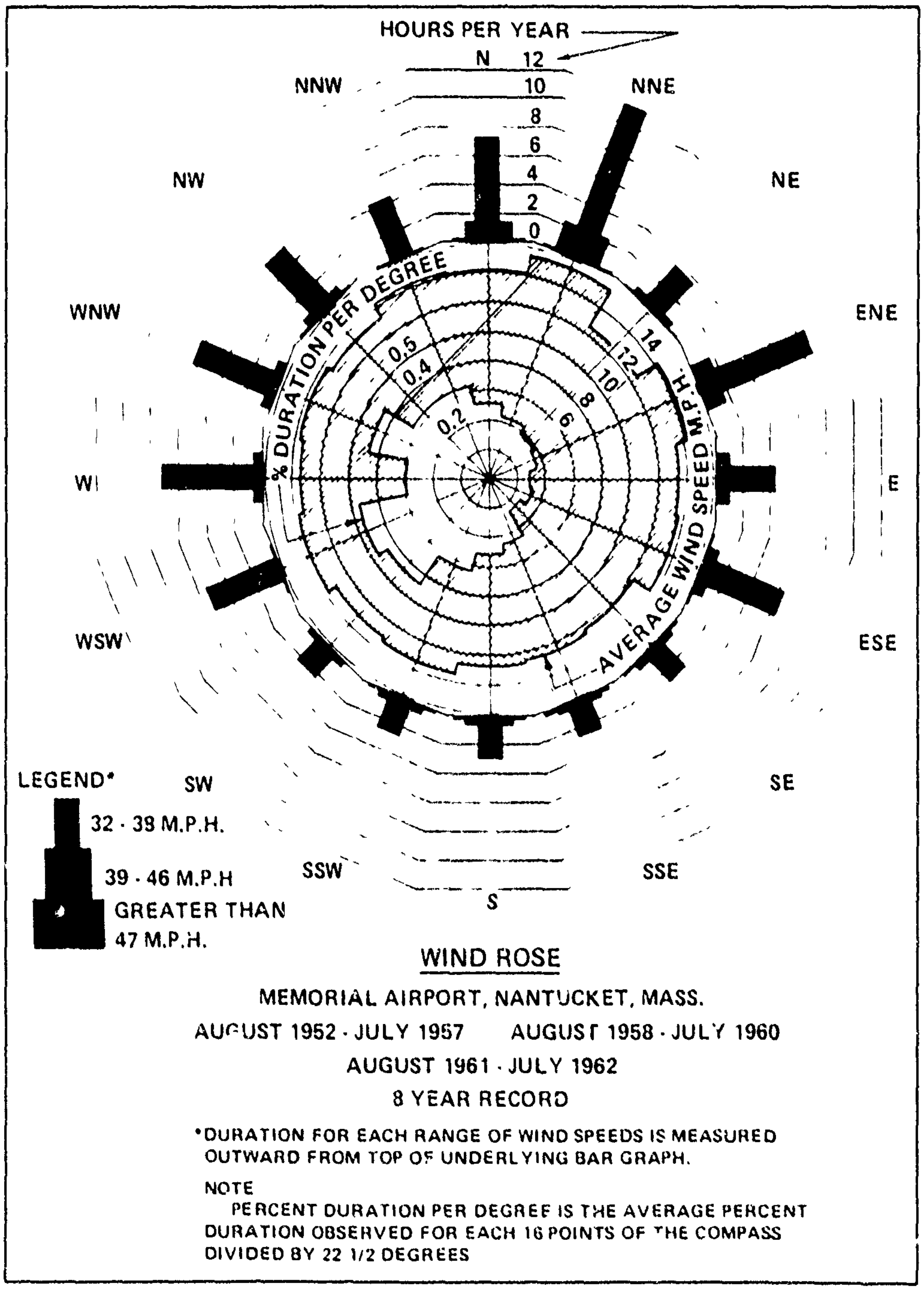
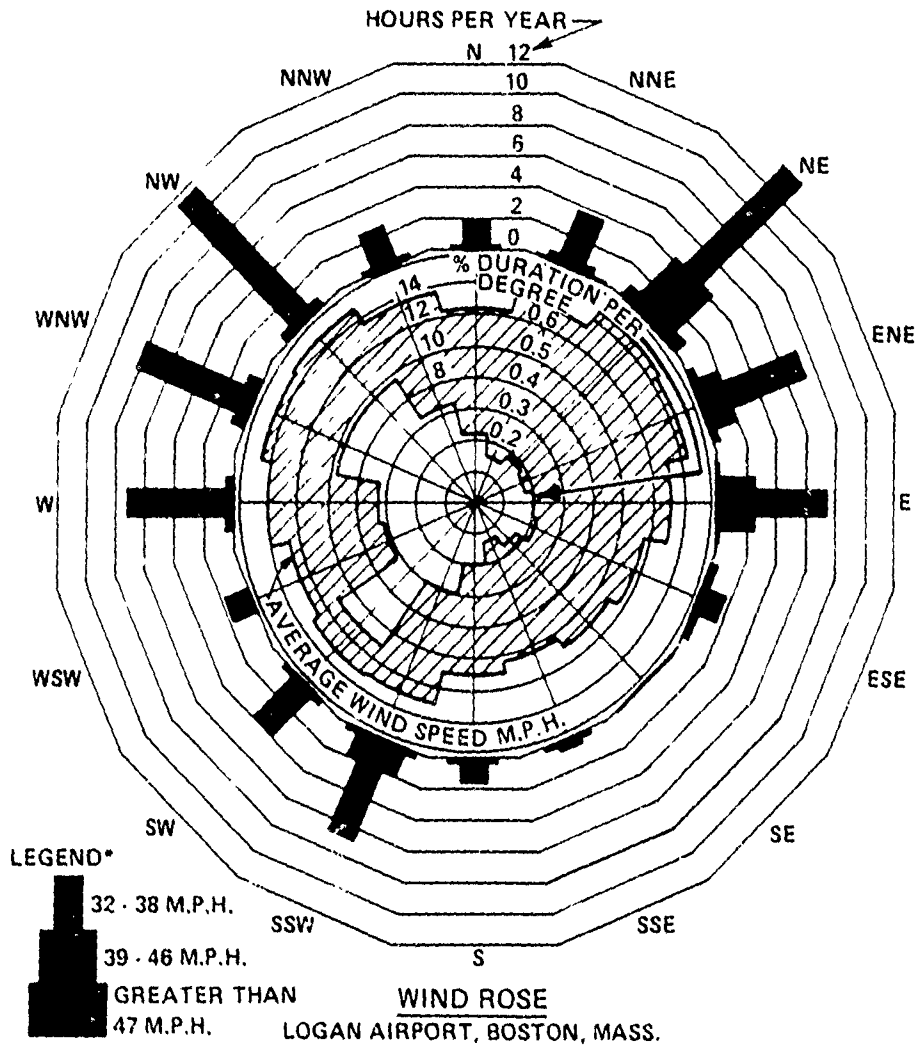


Figure 1-B9. Wind rose, Nantucket, Massachusetts



WIND ROSE
LOGAN AIRPORT, BOSTON, MASS.
OCTOBER 1949 - SEPTEMBER 1959
10 YEAR RECORD

*DURATION FOR EACH RANGE OF WIND SPEEDS IS MEASURED OUTWARD FROM TOP OF UNDERLYING BAR GRAPH.

NOTE:
PERCENT DURATION PER DEGREE IS THE AVERAGE PERCENT DURATION OBSERVED FOR EACH 16 POINTS OF THE COMPASS DIVIDED BY 22 1/2 DEGREES.

Figure 1-B10. Wind rose, Boston, Massachusetts

the exception of Alaska and possibly very northern New England where rebound may still be occurring. The rate of rise on the east coast has generally been 1 to 1-1/2 feet per century. This apparent change in sea level has been ascribed to a combination of increased water volume in the ocean from melting glaciers and subsidence of the land in some regions.

The Committee on Tidal Hydraulics, U.S. Army Corps of Engineers, made the following assessment of probable future changes in sea level:

> During the short period of record for which accurate tidal data are available on the North American continent, the rate of sea level rise is indicated to be accelerating. While the data are insufficient to justify statistical analysis, the following assumptions are believed to be appropriate for planning purposes:
>
> a. During the next 50 years local mean sea level will probably rise not less than 0.5 foot nor more than 1.5 feet above the present mean.
>
> b. Over a 100-year period the extent of rise is unlikely to be less than 1 foot and may be as much as 3 feet.

Thus, the present mean level of the sea at a given location along the coast can be expected to be several tenths of a foot higher than the National Geodetic Vertical Datum that was established as the mean sea level in 1929 and which remains fixed in time and space.

SECTION C

WAVE REFRACTION ANALYSIS

WAVE REFRACTION ANALYSIS

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INTRODUCTION

Longshore sediment transport induced by wave refraction is one of the primary mechanisms responsible for erosion and accretion on Cape Cod. To study wave refraction effects on Cape Cod's outer shores, a computer program that generates wave ray diagrams and predicts longshore movement of sediment was used. From this information, areas where sediment will erode or accrete under specified wave conditions can be identified. This section describes the most recent methods used at that time in the study area and discusses the results for representative wave conditions. Information on additional wave conditions can be found in the original reports (Isaji et al, 1976; Cornillon et al, 1976).

WAVE REFRACTION

As ocean waves approach the shore from deep water, the speed of wave propagation decreases with the ratio of water depth to wavelength. As a result, a portion of a wave front over relatively deep water travels faster than the portion of the wave front over relatively shallow water. This causes the direction of wave propagation to bend resulting in the wave crests becoming parallel to bottom contours (Figure 1-C1). The sea generally contains waves of various wavelengths. The longer waves are affected by this process further from shore than the shorter waves, but all waves tend to be nearly parallel to the beach at the water line. This process is called refraction. Refraction tends to focus wave energy on headlands and to decrease the intensity of wave energy landward of channels and other regions of greater than average depth.

The effects of water depth, deep water wave direction and wave period on refraction are well understood and can be readily computed, if sufficient information is available about the water depth and deep water wave conditions. Currents, including those due to the tides, variable wind conditions and wave amplitude, also affect wave refraction in the sea, but the current patterns vary continuously in time and the effects of wave amplitude are generally believed to be small. The effects of currents and wave amplitude were neglected in these wave refraction calculations. Neglecting the amplitude effect means that the tendency for focusing wave energy is overestimated by an unknown factor. No simple estimate of the effect of neglecting the currents can be made at this time. Because these secondary effects have been neglected in the calculations presented in this chapter,

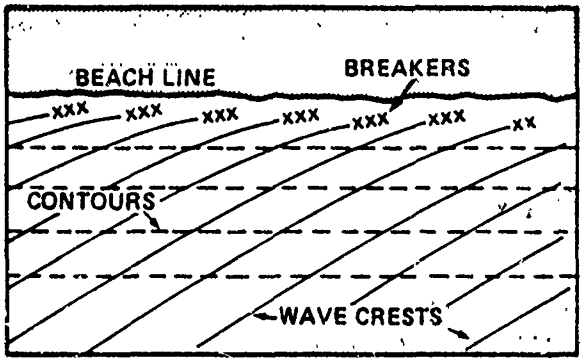


Figure 1-C1. Refraction along a straight beach with parallel bottom contours (After U.S. Army Coastal Engineering Research Center, 1975)

the computed results must be considered as approximations to reality. They are, however, about as accurate as present knowledge permits.

The breaking wave is rarely perfectly parallel with the shore, and the angle that the wave front makes with the shore produces a longshore current. The longshore current, in turn, transports sediment along the shore. The strength of the longshore current depends upon the height of the wave at breaking as well as on the angle between the breaking wave and the shore.

BATHYMETRIC DATA

Computer programs used to generate wave refraction information require both bathymetric (depth) data and deepwater wave characteristics as input. Bathymetric data obtained from Coast and Geodetic Survey charts were entered in the form of a square depth grid. The program uses this depth grid to calculate the water depth and the slope of the sea floor along each wave ray. A grid spacing of 0.25 nautical miles or fifteen seconds of latitude was selected for this study so that the spacing of the grid would approximate the spacing of the data points.

The Coast and Geodetic Survey charts were prepared as an aid to marine navigation, and the depths shown tend to be the minimum depth rather than representative values. These charts, however, were the only convenient source of depth data when these calculations were started. The National Oceanic and Atmospheric Administration (NOAA) is now assembling all of the depth data on magnetic tapes, and these data tapes will provide a superior source of depth data for future calculations.

WAVE CONDITIONS

The other information required for wave refraction analysis, deepwater wave characteristics (Figure 1-C2), includes wave period (the time for two successive wave crests to pass a given point), wave height (the vertical distance between the wave crest and the preceding trough), and wave direction. Wave period and wave direction are necessary for generating wave rays. Wave height, although not necessary for wave ray generation, is required for prediction sediment transport.

Information on wave period and direction is available from the Summary of Synoptic Meteorological Observations (SSMO). Wave period information is divided into the following intervals: less than 5.5 seconds, 5.5 to

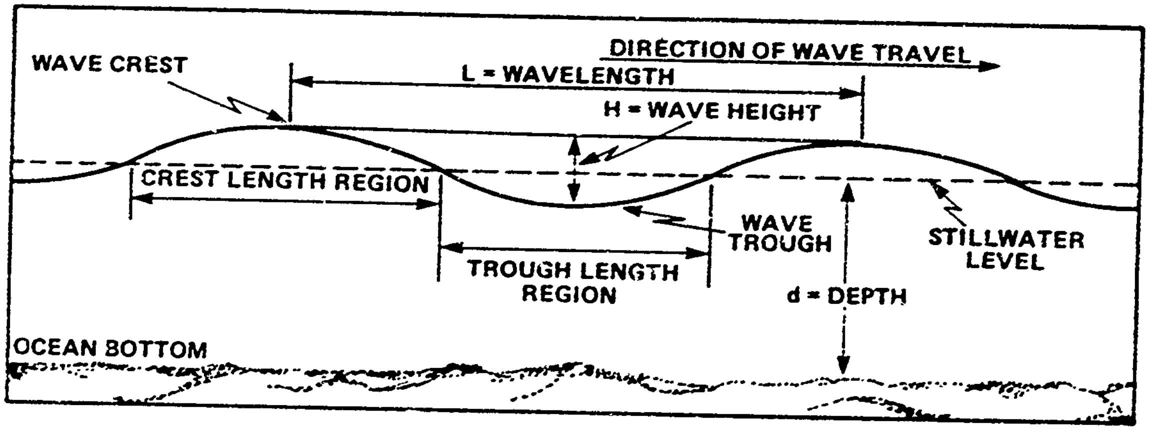


Figure 1-C2. Wave length, wave height and direction of propagation (After U.S. Army Coastal Engineering Research Center, 1975)

7.5 seconds, 7.5 to 9.5 seconds, 9.5 to 11.5 seconds and greater than 11.5 seconds. One representative wave period was chosen from each interval, and wave rays were propagated shoreward from the open ocean for waves with periods of 4, 6, 8, 10 and 12 seconds. These values were chosen near the lower end of each interval (except for the first interval) because the probability that a wave with a given period will occur decreases as the period increases.

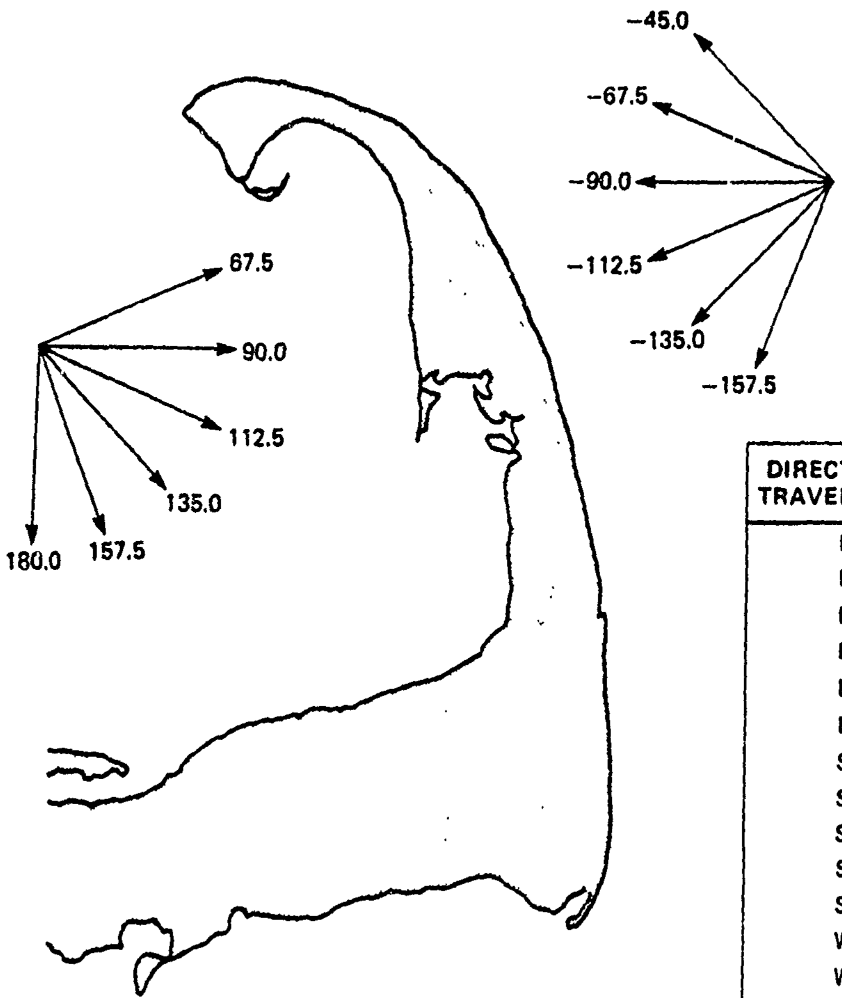
Representative wave heights were also chosen for use in model calculations. The calculations of the longshore current, longshore energy flux (the rate at which energy is transmitted parallel to the shoreline), and erosion/accretion rates were performed for the following deepwater wave heights: 1, 3, 5, 7, 9, 11 and 13 feet.

Waves approach Cape Cod from all directions. Not all of these waves, however, affect the study area. The wave directions investigated are indicated in Figure 1-C3. For each of these directions, a complete set of wave rays was propagated from deep water toward the shoreline exposed to the wave. For example, waves from the east were propagated shoreward from the Atlantic Ocean, and waves from the west were propagated toward the Provincetown shore from Cape Cod Bay.

For the open-ocean side of Cape Cod, deepwater waves moving north-northwest (-22.5 degrees) were not considered in this study for two reasons. First, the water is very shallow (less than 30 feet) for more than 35 nautical miles to the south-southeast of Nauset Beach, the main area exposed to these waves. For the wave refraction diagram generated by the computer program to be useful, the water wave propagated shoreward by the program should start in water at least as deep as one half of the wave length. This qualification would require a depth grid almost twice as large as the one used in this study if waves moving north-northwest were included. Secondly, as a wave moves through shallow water, it loses energy; i.e., the height of the wave decreases. For all but waves of the shortest periods (4 and 6 seconds) moving north-northwest, a substantial amount of the energy in the wave is removed before the wave gets to Nauset Beach. The wave, therefore, makes only a small contribution to the sediment transport on the easterly Cape Cod shoreline. For these reasons, it was felt that the increased cost associated with a larger depth grid was not warranted.

WAVE RAYS

As mentioned earlier, the longshore sediment transport depends on the angle that the breaking wave makes with the shoreline and on the height of the breaking wave (Figure 1-C4). The wave ray diagram can give a general feeling for the magnitude and direction of the longshore transport for any given deepwater condition. For example, in Figure 1-C5, the shoreline-breaker



DIRECTION WAVE TRAVELS TOWARD	ANGLE
N	0.0
NNE	22.5
NE	45.0
ENE	67.5
E	90.0
ESE	112.5
SE	135.0
SSE	157.5
S	180.0
SSW	-157.5
SW	-135.0
WSW	-112.5
W	- 90.0
WNW	- 67.5
NW	- 45.0
NNW	- 22.5

Figure 1-C3. Deepwater wave directions (After Isaji et al, 1976)

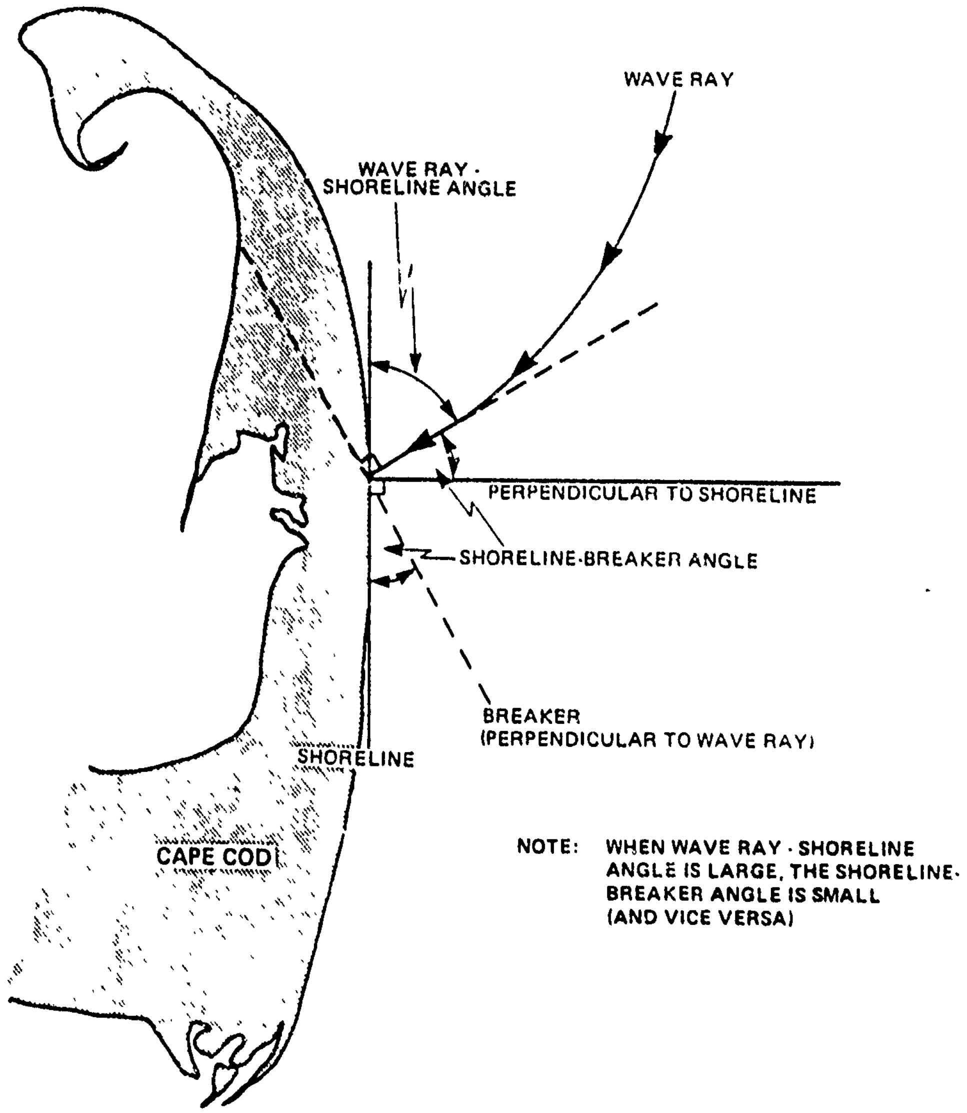


Figure 1-C4. Shoreline-breaker angle

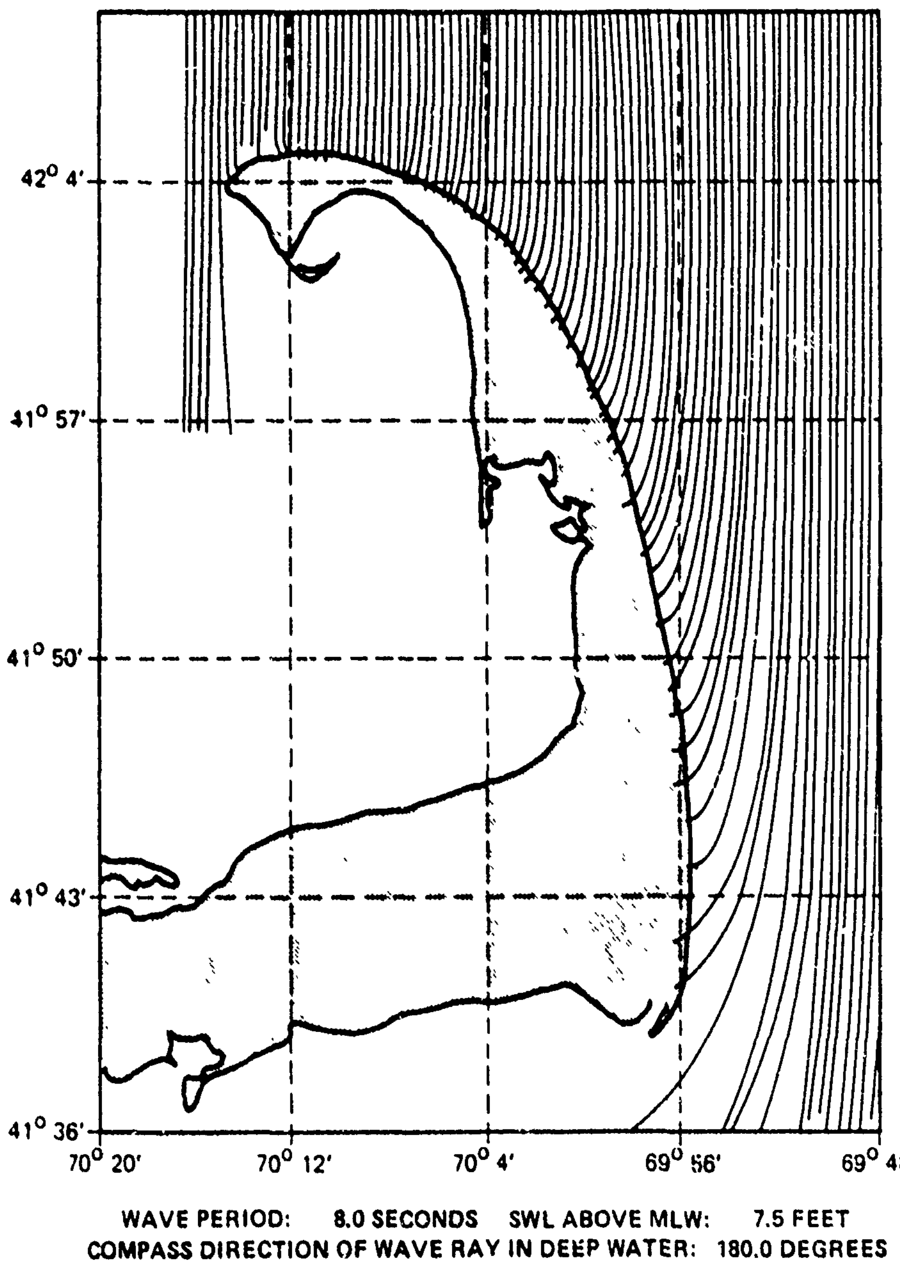


Figure 1-C5. Wave ray diagram for 8-second waves approaching Cape Cod from the north (After Isaji et al, 1976)

angle can be estimated at any point along the coast as the angle between the wave ray closest to the coastal point of interest and the perpendicular to the coast at that point.

The relative heights of the breaking waves along the shoreline can also be estimated. If the wave rays in shallow water are closer together than in deep water, the wave has been focused and the height of the breaking wave is higher than at those points where there is no focusing. Conversely, if the wave rays are farther apart in shallow water than in deep water, the wave has been defocused. Defocusing leads to a reduced amplitude.

For waves with an 8-second period approaching Cape Cod from the north, the wave ray diagram is given in Figure 1-C5. As this figure shows, the shoreline-breaker angle is very small on the northern shore of Provincetown, but it increases to the south, particularly between Eastham and Chatham. This increase in the shoreline-breaker angle should produce an increase in the longshore current magnitude, thus increasing the longshore sediment transport. Figure 1-C5 also shows that the wave rays are close together on the northern shore of Provincetown and more widely spaced (defocused) approaching Chatham. This implies that when 8-second waves approach Cape Cod from the north, breaker height decreases from Provincetown to Chatham. Decreasing breaker height should reduce the magnitude of the longshore current, thereby reducing the amount of longshore sediment transport.

LONGSHORE ENERGY FLUX AND EROSION CALCULATIONS

To calculate the erosion/accretion rate, it is necessary to estimate the longshore sediment transport. The simplest method available that fits existing field data reasonably well is to assume that longshore sediment transport is proportional to longshore energy flux. [For details of this calculation, refer to the original report (Cornillon et al, 1976).]

Given the longshore sediment transport for any pair of wave rays, it is possible to calculate the amount of sediment entering (accretion) or leaving (erosion) the area between these rays assuming no onshore/offshore sediment motion. This quantity, divided by the distance between the two rays, gives the average erosion/accretion per unit length in this region. For example, the longshore sediment transport at position A in Figure 1-C6 is 23,704 cubic yards per year while the longshore sediment transport at position B is 10,077 cubic yards per year. Therefore, 13,627 cubic yards or 17.7 cubic yards per foot of sediment per year are leaving the region between transect A and transect B. This means that if the surf zone (region between the shoreline and the breakers) is 500 feet wide, about 1 foot of sediment would be removed from the sea floor in this region in a typical year if the conditions in this example (wave direction, wave period and wave height persisted for an entire year.

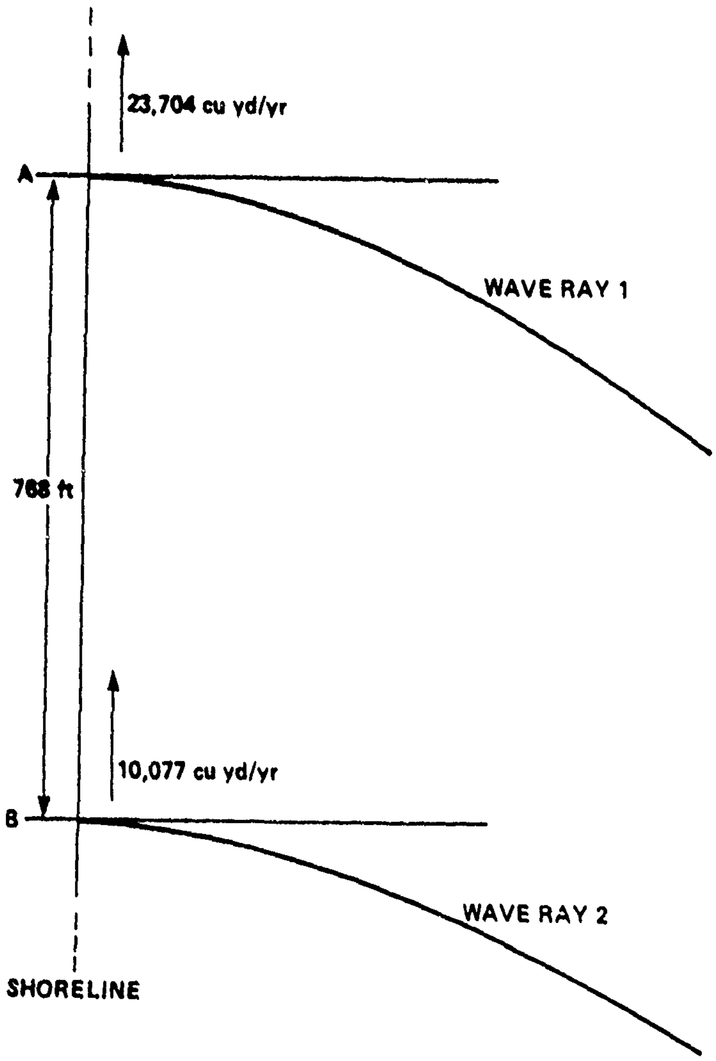


Figure 1-C6. Example of erosion/accretion calculation (After Cornillon et al, 1976)

DEEP WATER WAVE STATISTICS

The wind conditions that produce waves affecting Cape Cod are constantly changing. For this reason, the waves approaching Cape Cod vary in wave height, wave period and direction. It is necessary to know the fraction of time that each of the different deepwater wave height, wave period and wave direction combinations occurs in order to calculate the average value of the longshore current, the longshore energy flux and the erosion/accretion rate for one year. The erosion/accretion rate resulting from each set of deepwater conditions can be determined, as explained in the previous section. Because some wave conditions occur more frequently than others, it is necessary to weight the erosion/accretion rate resulting from the most frequent wave conditions more heavily than rates associated with less probable wave conditions. To accomplish this, the erosion/accretion rate for each wave condition is weighted by the probability that the given wave condition will occur.

Over a period of years, the U.S. Naval Weather Service Command and the National Physical Laboratory have obtained thousands of voluntary deepwater wave observations from ship crews who passed through various zones. The observations consisted of an estimate of the wave period, height and direction. In this study, the data have been combined into one set of predictions of the frequency of occurrence for each deepwater condition. These data are presented in Table 1-C1.

RESULTS

Sample Cases

For 8-second waves coming from the east at low tide, plots are included for a 1-foot deepwater wave (Figure 1-C7) and a 13-foot deepwater wave (Figure 1-C8). The main difference between the two is in the scale. There are also a few minor changes in the actual shape of the curves because the waves break farther from shore as they get larger, resulting in a different angle relative to the beach.

In the case of 6-second, 5-foot waves from the north (Figures 1-C9 and 1-C10), both a substantial longshore current and a longshore energy flux to the south occur along the entire eastward-facing coastline of Cape Cod, i.e., that part of the coastline south of 42°03'04" (Highland Beach) or the 30-mile mark. This is indicated in Figure 1-C10. One might expect the longshore current (and the longshore energy flux) to the south to have its largest value near the 10-mile mark (south of Nauset Harbor inlet) where the wave ray-shoreline angle is the smallest (breaker-shoreline angle the largest). It is interesting

Table 1-C1. Probability distribution deepwater wave statistics from the Summary of Synoptic Meteorological Observations (SSMO)

WAVE HEIGHT (ft)	WAVE DIRECTION	WAVE PERIOD (sec)				
		4	6	8	10	12
1.0	N	0.022950	0.001950	0.0	0.0	0.0
1.0	NNE	0.019760	0.003380	0.0	0.0	0.0
1.0	NE	0.012710	0.002100	0.0	0.0	0.0
1.0	ENE	0.006030	0.000510	0.0	0.0	0.0
1.0	E	0.004650	0.000450	0.0	0.0	0.0
1.0	ESE	0.007340	0.000750	0.0	0.0	0.0
1.0	SE	0.008740	0.000750	0.0	0.0	0.0
1.0	NNW	0.0	0.0	0.0	0.0	0.0
1.0	NW	0.0	0.0	0.0	0.0	0.0
1.0	WNW	0.0	0.0	0.0	0.0	0.0
1.0	W	0.0	0.0	0.0	0.0	0.0
1.0	WSW	0.0	0.0	0.0	0.0	0.0
3.0	N	0.0	0.0	0.0	0.0	0.0
3.0	NNE	0.0	0.0	0.0	0.0	0.0
3.0	NE	0.0	0.0	0.0	0.0	0.0
3.0	ENE	0.0	0.0	0.0	0.0	0.0
3.0	E	0.0	0.0	0.0	0.0	0.0
3.0	ESE	0.0	0.0	0.0	0.0	0.0
3.0	SE	0.0	0.0	0.0	0.0	0.0
3.0	NNW	0.028082	0.0	0.0	0.0	0.0
3.0	NW	0.031050	0.0	0.0	0.0	0.0
3.0	WNW	0.052055	0.0	0.0	0.0	0.0
3.0	W	0.055137	0.0	0.0	0.0	0.0
3.0	WSW	0.055822	0.0	0.0	0.0	0.0
5.0	N	0.014400	0.011020	0.002700	0.000670	0.000670
5.0	NNE	0.014460	0.011580	0.002260	0.000730	0.000610
5.0	NE	0.012450	0.009480	0.002170	0.000710	0.000820
5.0	ENE	0.010110	0.007030	0.002160	0.000930	0.000950
5.0	E	0.008550	0.005850	0.002100	0.002250	0.000450
5.0	ESE	0.011360	0.008220	0.002410	0.001000	0.000880
5.0	SE	0.013910	0.009030	0.002660	0.000750	0.001050
5.0	NNW	0.0	0.0	0.0	0.0	0.0
5.0	NW	0.0	0.0	0.0	0.0	0.0
5.0	WNW	0.0	0.0	0.0	0.0	0.0
5.0	W	0.0	0.0	0.0	0.0	0.0
5.0	WSW	0.0	0.0	0.0	0.0	0.0

Table 1-C1. Probability distribution deepwater wave statistics from the Summary of Synoptic Meteorological Observations (SSMO) (Continued)

WAVE HEIGHT (ft)	WAVE DIRECTION	WAVE PERIOD (sec)				
		4	6	8	10	12
7.0	N	0.001800	0.004800	0.002920	0.000450	0.000150
7.0	NNE	0.001420	0.004480	0.002230	0.001010	0.000580
7.0	NE	0.001270	0.004050	0.002430	0.000970	0.000480
7.0	ENE	0.001130	0.003500	0.002660	0.000780	0.000280
7.0	E	0.000820	0.002620	0.002100	0.000600	0.000220
7.0	ESE	0.001260	0.004180	0.002910	0.000850	0.000280
7.0	SE	0.001570	0.005660	0.003560	0.001080	0.003370
7.0	NNW	0.0	0.018151	0.0	0.0	0.0
7.0	NW	0.0	0.019406	0.0	0.0	0.0
7.0	WNW	0.0	0.006735	0.0	0.0	0.0
7.0	W	0.0	0.007306	0.0	0.0	0.0
7.0	WSW	0.0	0.005137	0.0	0.0	0.0
9.0	N	0.0	0.000900	0.001570	0.001200	0.001050
9.0	NNE	0.0	0.000640	0.001200	0.000820	0.000420
9.0	NE	0.0	0.001230	0.001310	0.001200	0.000600
9.0	ENE	0.0	0.002320	0.001470	0.001480	0.000950
9.0	E	0.0	0.004570	0.001350	0.000670	0.001200
9.0	ESE	0.0	0.001760	0.001780	0.000980	0.001380
9.0	SE	0.0	0.001650	0.003150	0.001570	0.001350
9.0	NNW	0.0	0.0	0.0	0.0	0.0
9.0	NW	0.0	0.0	0.0	0.0	0.0
9.0	WNW	0.0	0.0	0.0	0.0	0.0
9.0	W	0.0	0.0	0.0	0.0	0.0
9.0	WSW	0.0	0.0	0.0	0.0	0.0
11.0	N	0.0	0.0	0.0	0.0	0.0
11.0	NNE	0.0	0.0	0.0	0.0	0.0
11.0	NE	0.0	0.0	0.0	0.0	0.0
11.0	ENE	0.0	0.0	0.0	0.0	0.0
11.0	E	0.0	0.0	0.0	0.0	0.0
11.0	ESE	0.0	0.0	0.0	0.0	0.0
11.0	SE	0.0	0.0	0.0	0.0	0.0
11.0	NNW	0.0	0.0	0.0	0.0	0.0
11.0	NW	0.0	0.0	0.0	0.0	0.0
11.0	WNW	0.0	0.0	0.0	0.0	0.0
11.0	W	0.0	0.0	0.0	0.0	0.0
11.0	WSW	0.0	0.0	0.0	0.0	0.0

Note: Waves with 13.0-foot wave heights had 0.0 probability of occurrence for the wave periods and wave directions listed in the table.

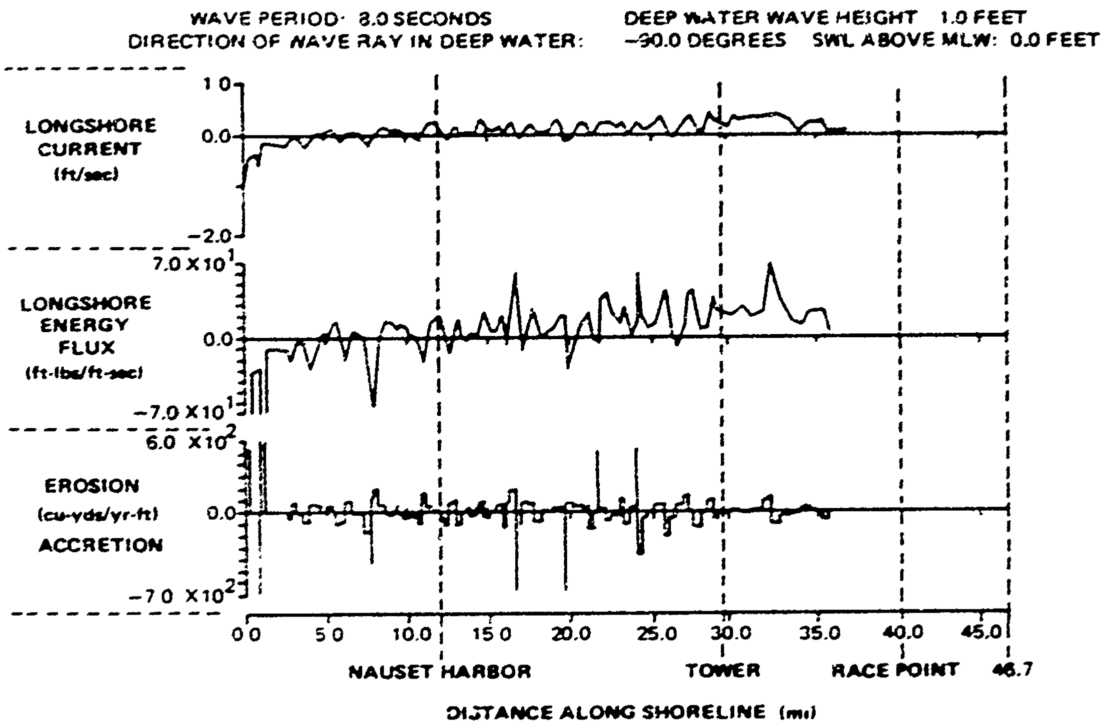


Figure 1-C7. Longshore current, longshore energy flux and erosion/accretion for 1-foot, 8-second waves approaching Cape Cod from the east (After Cornillon et al, 1976)

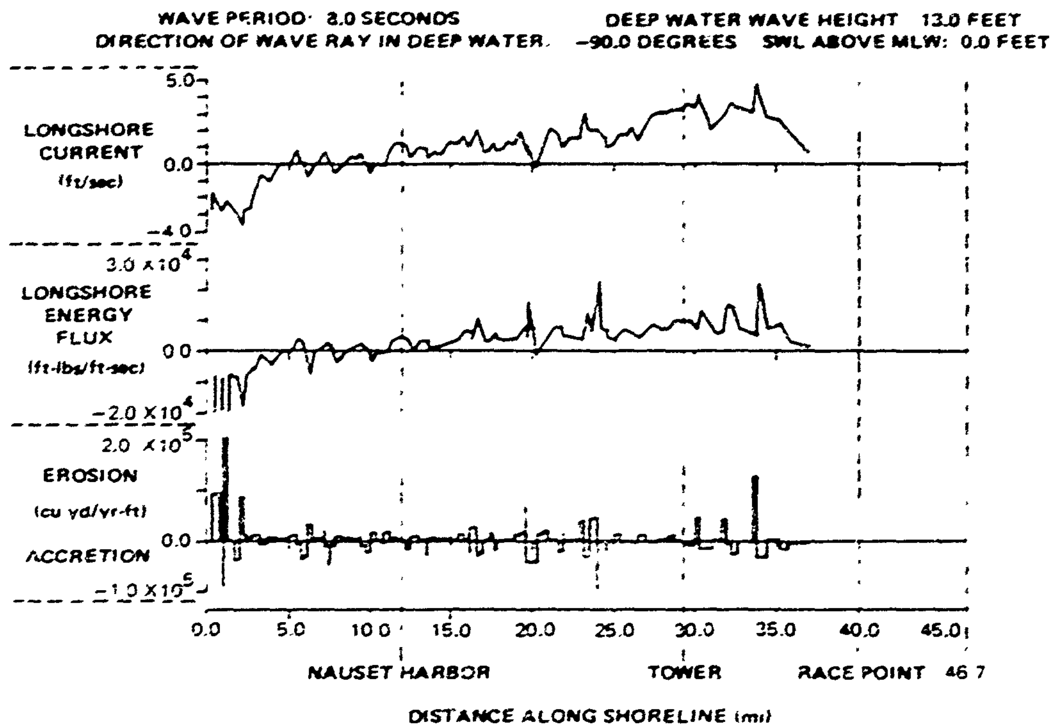


Figure 1-C8. Longshore current, longshore energy flux and erosion/accretion for 13-foot, 8-second waves approaching Cape Cod from the east (After Cornillon et al, 1976)

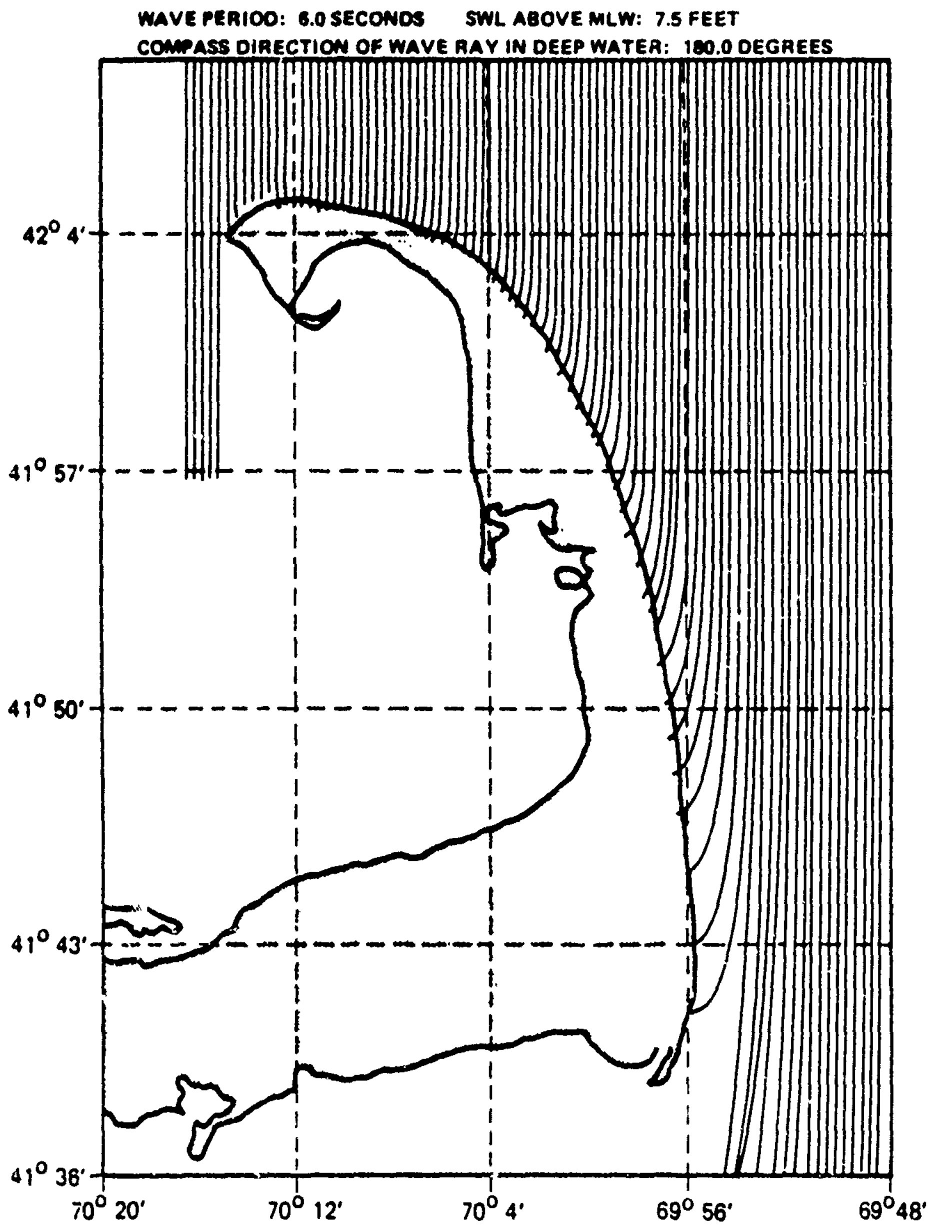


Figure 1-C9. Wave ray diagram for 6-second waves approaching Cape Cod from the north (After Isaji et al, 1976)

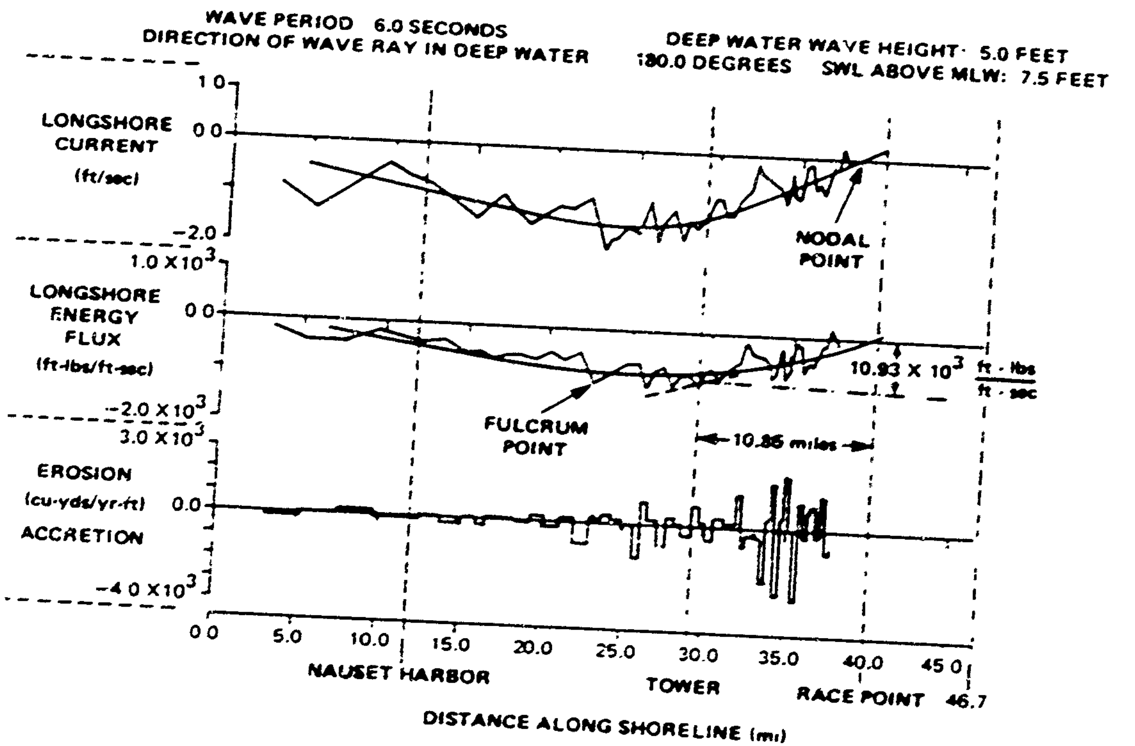


Figure 1-C10. Longshore current, longshore energy flux and erosion/accretion for 5-foot 6-second waves approaching Cape Cod from the north (After Cornillon et al, 1976)

to note, however, that a smooth curve fit through the longshore current (or the longshore energy flux) curve indicates a maximum negative value at approximately the 27-mile mark (north of Ballston Beach) (Figure 1-C10). This maximum results from the fact that longshore current and longshore energy flux depend on the wave height at breaking as well as on the breaker-shoreline angle. As the separation of the wave rays near the shoreline in the wave refraction diagram (Figure 1-C9) shows, the wave height is substantially larger near the 27-mile mark (north of Ballston Beach) than near the 10-mile mark (south of Nauset Harbor inlet) while the breaker-shoreline angle is only somewhat larger.

The point at which the longshore sediment transport attains either a maximum positive or negative value (27-mile mark in Figure 1-C10) is referred to as a <u>fulcrum point</u>. This is a point at which there is no net erosion or accretion but at which sediment transport may be substantial. For example, for 6-second, 5-foot waves from the north, a fulcrum point occurs at approximately the 27-mile mark (north of Ballston Beach). The longshore energy flux at this point is about 807 foot pounds per foot second in a southerly direction, and the longshore sediment transport rate is about 6.50×10^6 cubic yards per year. This means that if these wave conditions were to persist for an entire year, approximately 6 million cubic yards of sediment would move past the fulcrum point with zero erosion or accretion (assuming no onshore-offshore motion).

Another important feature of these plots is the decrease in the magnitude of the longshore current (and longshore energy flux which, in this study, is assumed to be proportional to longshore sediment transport) from a maximum at approximately the 27-mile mark (north of Ballston Beach) to zero at approximately the 37-mile mark (east of Race Point Coast Guard Station). The point at which the longshore current or sediment transport changes direction is referred to as a <u>nodal point</u>. (See Table 1-C2 and 1-C3.)

Two different conditions arise at a nodal point depending on the slope of the longshore energy flux curve as it crosses the axis. If the slope is positive (as in Figure 1-C10), the direction of the longshore current and the longshore sediment transport on either side of the nodal point is away from the nodal point. To supply the longshore current away from the nodal point, there must be an onshore current. This will result in an onshore sediment drift. Whether erosion caused by the longshore current or deposition caused by the onshore current dominates depends on several local conditions such as the bottom slope, the spatial rate of change of the longshore current, etc. If the slope of the longshore energy flux and current is negative, the opposite condition arises - sediment moves alongshore towards the nodal point with rip currents moving sediment offshore from the vicinity of the nodal point.

Examples of sediment transport, sediment transport rate and erosion rate calculations can be found in the original report (Cornillon et al, 1976).

Table 1-C2. Suggested locations of the nodal point on the eastern shore of Cape Cod

STUDY	LOCATION
Schalk, 1938	Shoreline opposite the mouth of the Pamet River, Truro
Hartshorn et al, 1967	Near the center of the outer Cape
Fisher, 1972	Newcomb Hollow Beach, Wellfleet (just south of Gull Pond)
Gatto, 1975	Between Salt Meadow and the North Truro Air Force Station
Cornillon et al, 1976	LeCount Hollow Beach, Wellfleet

Table 1-C3. Location of the nodal point on the Eastern shore of Cape Cod for waves from one direction, wave refraction analysist (after Cornillon et al, 1976)

DIRECTION FROM WHICH WAVE IS COMING	LOCATION OF NODAL POINT (miles north of the tip of Nauset Beach, Chatham)
NW	39
NNW	38
N	37
NNE	34
NE	29
ENE	24
E	9
ESE	2

Average Yearly Sediment Transport Rates

From a geological point of view, the most interesting results from a study of this type are not the locations of the nodal and fulcrum points for each of the individual deepwater wave conditions considered but rather the nodal and fulcrum points associated with the yearly average longshore sediment transport. To obtain the average yearly longshore sediment transport rate, the longshore sediment transport rate for each of the individual deepwater wave conditions calculated was weighted by the probability of that condition's occurring and then summed over all conditions run.

The distribution of the various deepwater wave states is derived from the data observed by ships in passage [the Summary of Synoptic Meteorological Observations (SSMO)]. This distribution will be biased away from storm conditions, a deficiency that should be kept in mind while analyzing the results. In addition, bottom friction has been neglected. Because SSMO observations are biased toward smaller wave heights, these two errors tend to compensate for one another.

The largest predicted sediment transport rate (5.25 million cubic yards per year) is to the south of the 1-mile mark (near Chatham Harbor entrance) with correspondingly high erosion and accretion rates to either side of this point. The sediment transport rates and erosion/accretion rates over most of the rest of the coastline are more reasonable; for example, from about the 5-mile mark (on Nauset Beach east of Allen Point) to the 12-mile mark (Nauset Harbor inlet), the longshore transport rate to the south is fairly constant at 675×10^3 cubic yards per year with little erosion on the average. From the 12-mile mark (Nauset Harbor inlet) to about the 33-mile mark (Pilgrim Heights area), the erosion rate is nearly constant at about 13.5 cubic yards per year per linear foot of shoreline. This eroded material moves to the south below the 20-mile mark (near LeCount Hollow Beach) and to the north above the 20-mile mark. Most of it is deposited on the southern tip of the study area and from about the 33-mile mark (Pilgrim Heights area) to the 37-mile mark (east of Race Point Coast Guard Station). The maximum sediment transport rate of 1.4 million cubic yards per year from south to north occurs at about the 33-mile mark (Pilgrim Heights area).

The predicted erosion/accretion rates using the SSMO statistics compare quite favorably with erosion/accretion observations made by Zeigler in 1957 (Zeigler et al, 1964). In that study the erosion rate was found to be fairly constant from the entrance to Nauset Harbor (12-mile mark) to Highland Lighthouse. At about Highland Light the rate of erosion decreases, reaching zero at approximately the 33-mile mark (Pilgrim Heights area) after which accretion occurs. This means that the 33-mile mark is a fulcrum point. The predicted fulcrum point is at the 32-mile mark.

The erosion rate observed over the 29,400 yards between Nauset Spit and Pilgrim Lake (the study area for Zeigler's observation) is 847,632 cubic yards of sediment per year from the cliffs and from below the sea. This corresponds to an average erosion rate of 9.6 cubic yards per year per linear foot of shoreline, which compares reasonably well with the predicted rate of 13.5 cubic yards per year per linear foot of shoreline.

DETERMINATION OF PROJECTED SHORELINE

The procedure used to determine the rate of retreat or advance of the shoreline is outlined in Figure 1-C11. The first step is to cut the large spikes out of the original data (Figure 1-C12) because they are caused by the improper termination of a wave ray and, in general, do not represent a real condition. If the spikes are not removed, they introduce unreasonably large distortions in the subsequent smoothing steps. The truncated data are shown in Figure 1-C13.

Following truncation the data are passed through a low-pass filter to remove additional high frequency noise. This procedure, causes a phase shift to the right which is partially removed by passing the filtered data backward through the same filter, again reducing the high frequency components but also shifting the data, this time to the left. The truncated, forward-backward filtered data are shown in Figure 1-C14.

Finally, the portion of the data corresponding to the region in which Zeigler collected data was averaged and set equal to the corresponding average of Zeigler's observations. These two data sets are compared in Figure 1-C15. Note the excellent agreement in the area from the 20-mile mark to the 32-mile mark. The difference at the 12-mile mark is due to the fact that the wave refraction model considers mainly the lower spit at Nauset while Zeigler considered the upper spit. Furthermore, Zeigler is not confident of his data in this region.

The final product of the wave refraction model is the yearly erosion/accretion rate along the coast and the predicted advance or retreat of the shoreline during the next 50 years. These results are presented in the Shoreline Predictions section.

PROCESSING OF EROSION/ACCRETION DATA TO OBTAIN THE YEARLY CHANGE IN SHORELINE

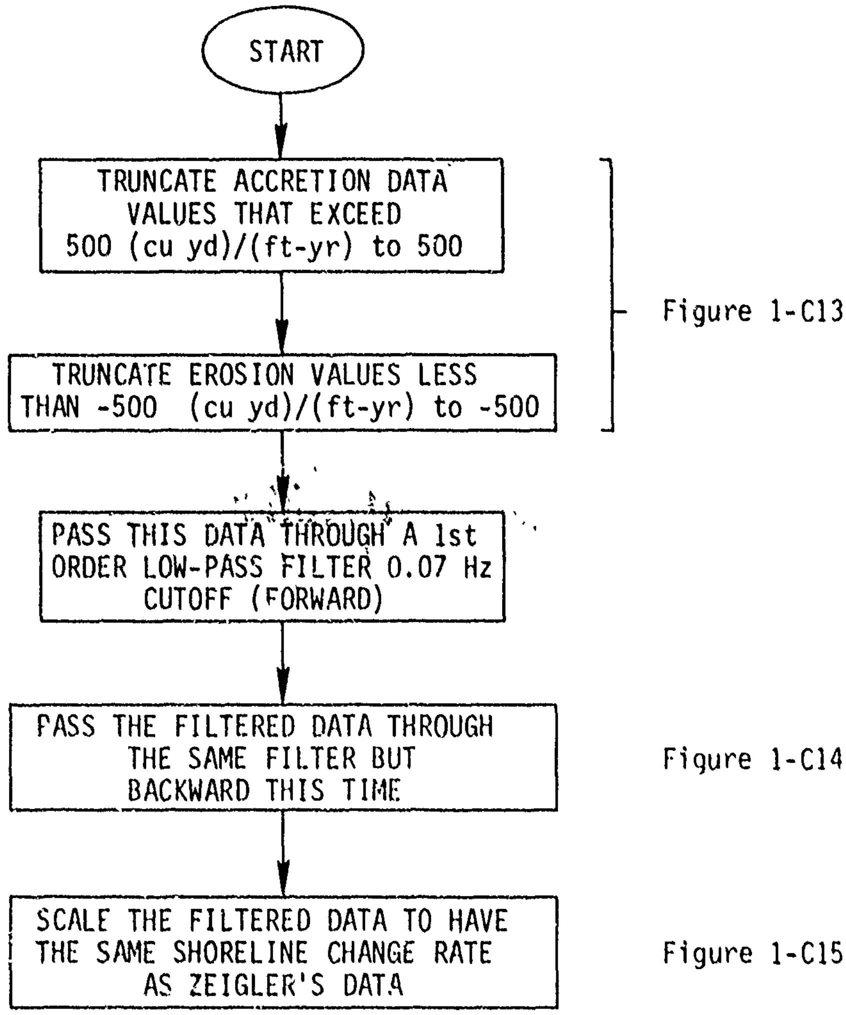


Figure 1-C11. Procedure for projecting shoreline changes

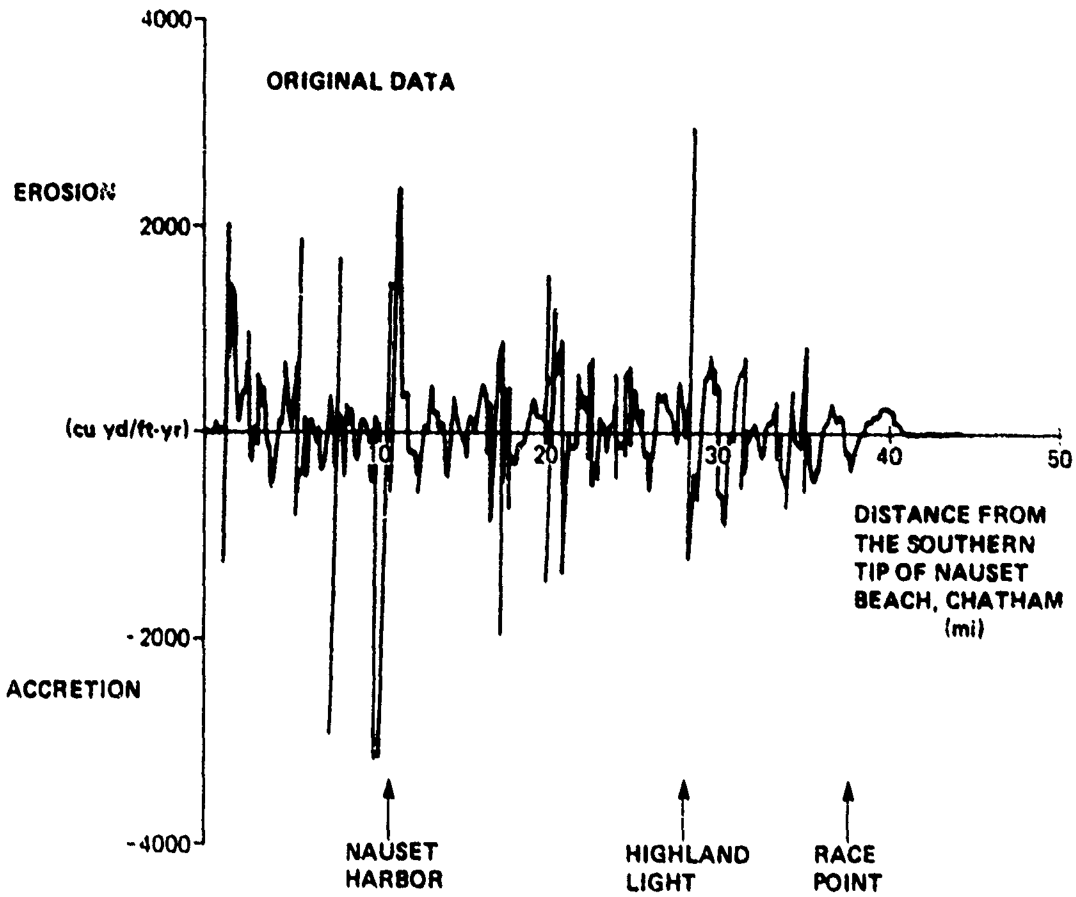


Figure 1-C-12. Original erosion/accretion data

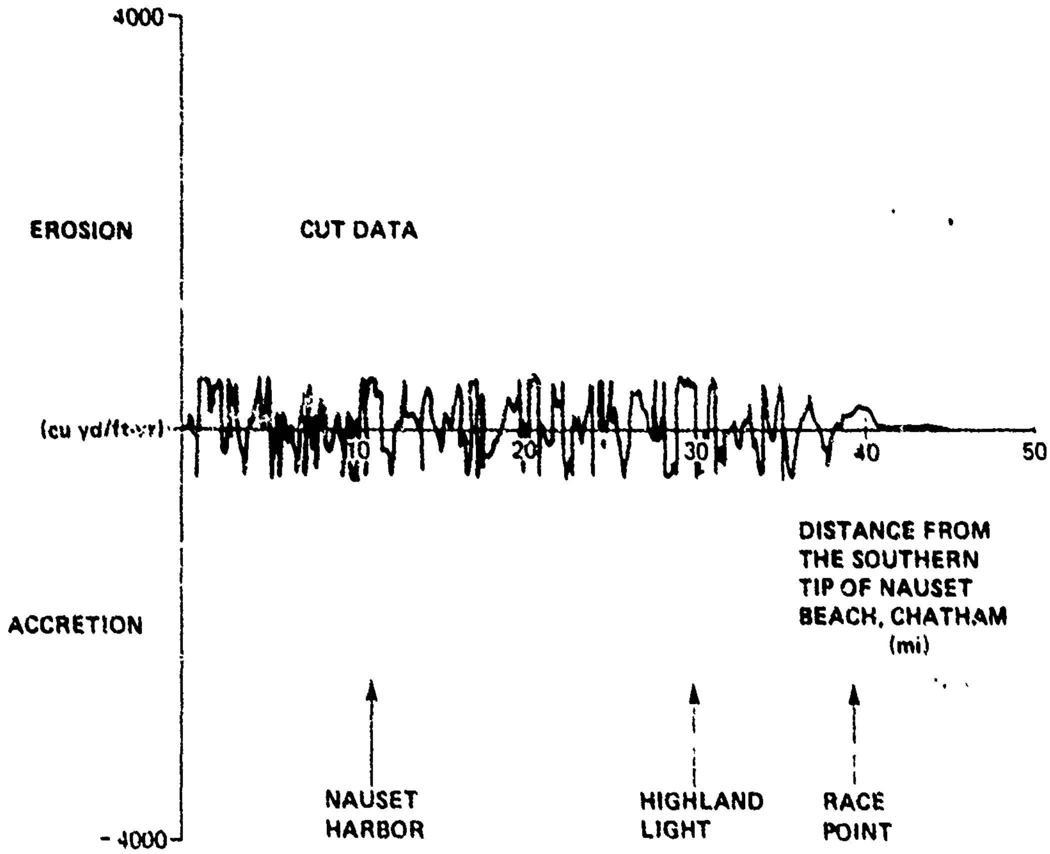


Figure 1-C13. Erosion/accretion data after truncation of values greater than 500 or less than -500 cubic yards per foot year

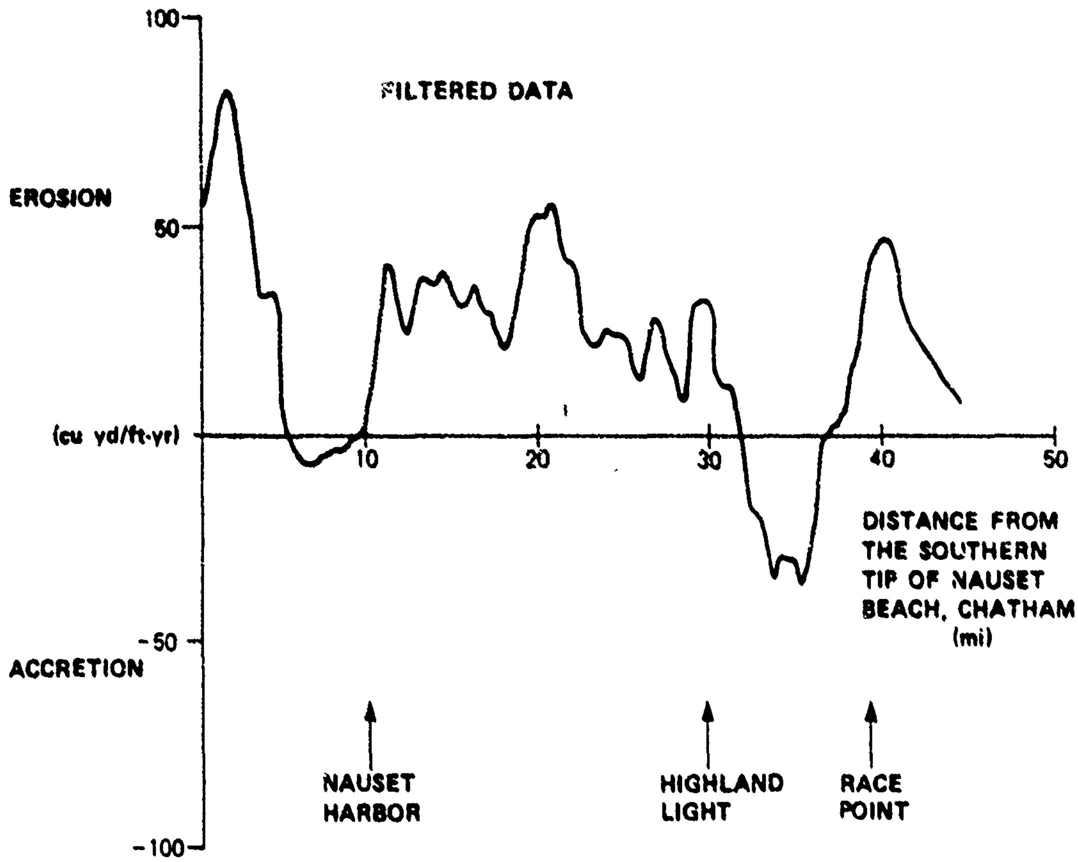


Figure 1-C14. Truncated, forward-backward filtered data

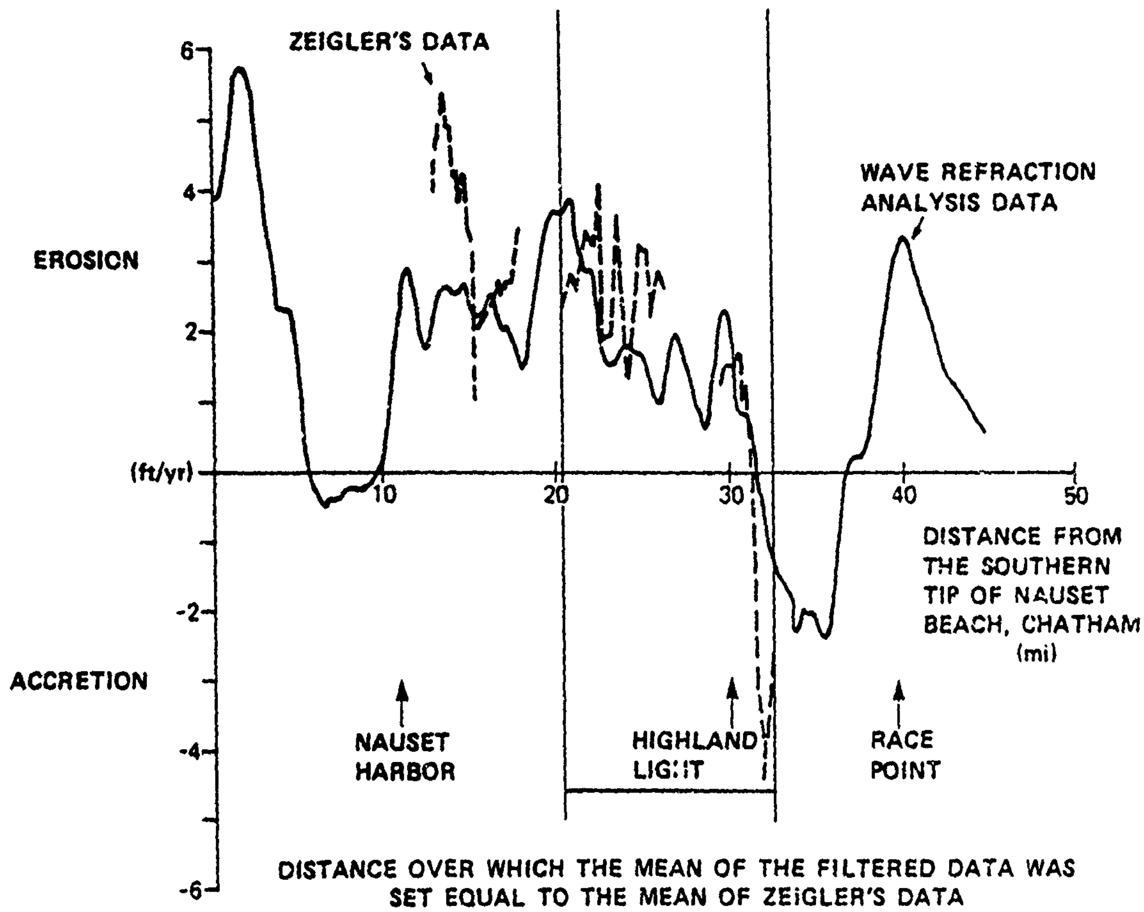


Figure 1-C15. Comparison of Zeigler's data with wave refraction analysis data

SECTION D

SHORELINE CHANGES

SHORELINE CHANGES

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SHORELINE CHANGES

INTRODUCTION

Since its formation, Cape Cod has been constantly changing. Some of the changes in the Cape's shoreline that occurred before recorded history can be inferred from geological evidence present on the Cape today. In other areas, the information about shoreline changes must come from historical records, early charts, and aerial photographs that can be compared with the present shoreline.

Maps showing historical shoreline changes for the easterly shores of Cape Cod from Long Point in Provincetown to the northern end of Monomoy Island, Chatham, have been prepared by the New England Division, U.S. Army Corps of Engineers. These maps, which are a compilation of various maps and aerial photographs developed between 1835 and 1974, show the movement of the mean-high-water shoreline. Portions of these maps are included in the shoreline-change discussions in this chapter.

The earliest maps available were developed in 1835. Other years of record are 1854, 1888, 1909, 1938, 1952, 1971, and 1974. Maps previous to 1938 were drawn from actual field surveys by the Coast and Geodetic Survey and the Corps of Engineers. With the advent of the airplane, aerial photography replaced surveys; the 1938, 1952, 1971, and 1974 shorelines were determined from mosaic aerial photographs with regulated ground control.

Problems can arise when comparing shorelines with those of other years. Because early shoreline maps were developed from actual land surveys, comparing the maps may produce inaccurate results if the surveys were conducted over a long period of time. The elapsed time increases the possibility of inaccuracy. Also, the mean-high-water shoreline can vary up to several hundred feet in some areas, depending on the time of year the survey is taken. In most instances, there is no indication of the season in which the surveys were conducted. Finally, in areas where both erosion and accretion occur, the maps become confusing and in some cases illegible. For these reasons, the shoreline-change maps are used to illustrate coastal changes that have occurred and they are not used for calculating erosion and accretion rates.

The shorelines of 1938, 1952, 1971, and 1974, which were developed from aerial photographs, are much more accurate for comparison purposes because the exact dates, time of year, and tidal conditions are known. Aerial photography also allows the entire coastline to be mapped within minutes, rather than months or possibly years (as was necessary for land surveys), eliminating a large source of error. L. W. Gatto (1975) of the U.S. Army Cold Regions Research Experimental Laboratory (CRREL) performed a detailed analysis of erosion and accretion rates based on

the aerial photographs. The results of his study are included in this discussion and are presented in Figures A through F at the end of this section.

THE GREAT HOOK OF THE PROVENCELANDS

Shoreline-change information for most of Cape Cod's easterly shores must be gained from historical charts and aerial photographs. The area north of High Head in Truro, however, is unique because the entire area was built by sand transported north along the coast of Cape Cod. Zeigler et al (1965) have investigated the formation of the Great Hook of the Provincelands and identified the probable phases of its development. Therefore, shoreline changes in the Provincetown area can be inferred back beyond historical records.

All of Cape Cod north and west of High Head in Truro was formed between 6,000 years ago and the present time (Zeigler et al, 1965). Prior to about 6,000 years ago, littoral transport on Cape Cod's outer shores was southward because Georges Bank and Nantucket Shoals intercepted waves coming from the east and southeast that would have produced northerly sediment transport along the coast. When sea level rose sufficiently to enable waves to cross Georges Bank and Nantucket Shoals, sediment began to move northward and build the Provincelands hook (Zeigler et al, 1965).

Sand carried north along the coast formed a narrow spit that grew longer and curved toward the southwest. Slowly the hook grew outward and upward with rising sea level as shown in Figure 1-D1. About 2,000 years ago, deposition patterns in the Provincelands changed; additional material transported into the area extended the northerly coast seaward, widening the hook (Zeigler et al, 1965). Some of the material reaching Race Point was transported southeastward past Herring Cove, where it formed a sand spit, now known as Long Point, that curves to the east and northeast (Strahler, 1966).

Changes in Provincetown's coastline and in the coastline of adjacent areas are evident in the comparison of present and historical charts (Figure 1-D2). Pilgrim Lake, Long Point, Herring Cove, Hatches Harbor, Race Point, and High Head graphically illustrate the changes occurring on Cape Cod's shores.

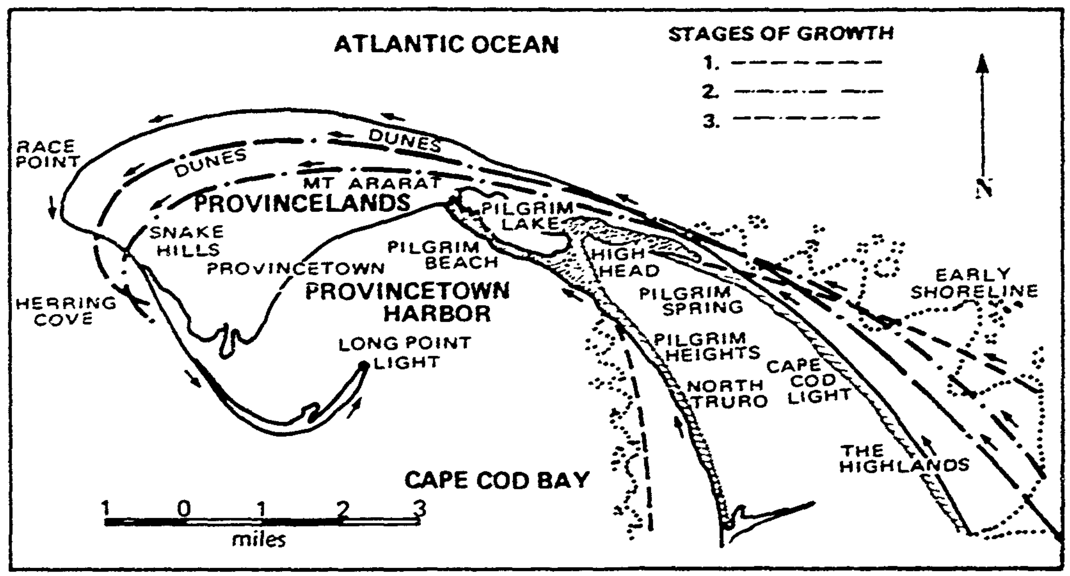


Figure 1-D1. Growth of the Provincelands hook (After Strahler, 1966)

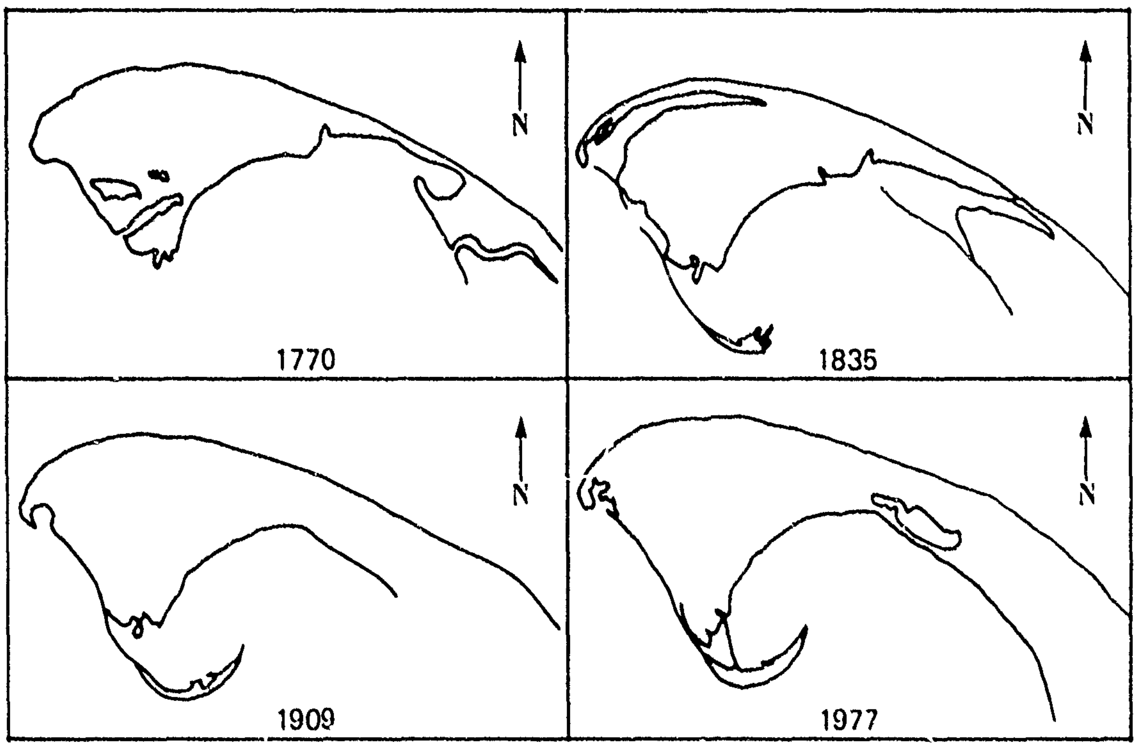


Figure 1-D2. Provincetown coastline, 1770-1977

Priglim Lake

As shown on the chart for 1770, Pilgrim Lake was originally a bay called East Harbor. Gradually, the spit at the southeastern end of the harbor grew, and in 1869 it was joined to the land closing the narrow inlet forming Pilgrim Lake and the present baymouth bar (Strahler, 1966).

Long Point

Long Point is the end of a sand spit that shelters Provincetown Harbor from waves produced by southerly winds blowing across Cape Cod Bay (Strahler, 1966). Although not shown on the 1770 chart, the spit is well-developed on the 1833 and 1835 charts (Figures 1-D3 and 1-D2). The general trend of changes in Long Point is shown in Figure 1-D3. Spits generated on the outer edge of the original spit have caused it to widen. This process is continuing on the outer shore of Long Point, as shown in the 1971 composite aerial photograph (Figure 1-D4).

The area around Long Point Lighthouse is principally a low-lying sand spit; dunes barely reach several feet above sea level. There are no trees, but scattered brush retains the sand. Although frequently overtopped under storm conditions, the spit is less susceptible to storm damage than other parts of the outer Cape because it is protected from the open ocean in nearly all directions. Because of this protection, Long Point is basically a stable area in terms of erosion and accretion. Continual minor changes counteract each other, leaving Long Point with a relatively stable appearance.

Herring Cove

Herring Cove Beach, which has been called both Provincetown Beach and New Beach, is located at the far western end of the Provincelands (Fisher, 1972). Although no cove exists at this location now, the charts for 1833 and 1848 show a cove separated from the sea by sand spits with a narrow inlet. Gradually this cove has filled in as sand transported along the coast has been deposited; the 1974 coastline, drawn over the 1833 chart, shows the effect of the deposition (Figure 1-D5).

Herring Cove Beach is supplied by sand eroded from the scarp at Highland, 10 nautical miles to the east. Sand is transported northwesterly to Race Point and then southeasterly from Race Point to Herring Cove Beach. The beach, which is frequently a series of steps, often lacks a foreshore, berm, and backshore (Fisher, 1972). Recently, erosion has threatened the asphalt area behind the beach (Figure 1-D6).

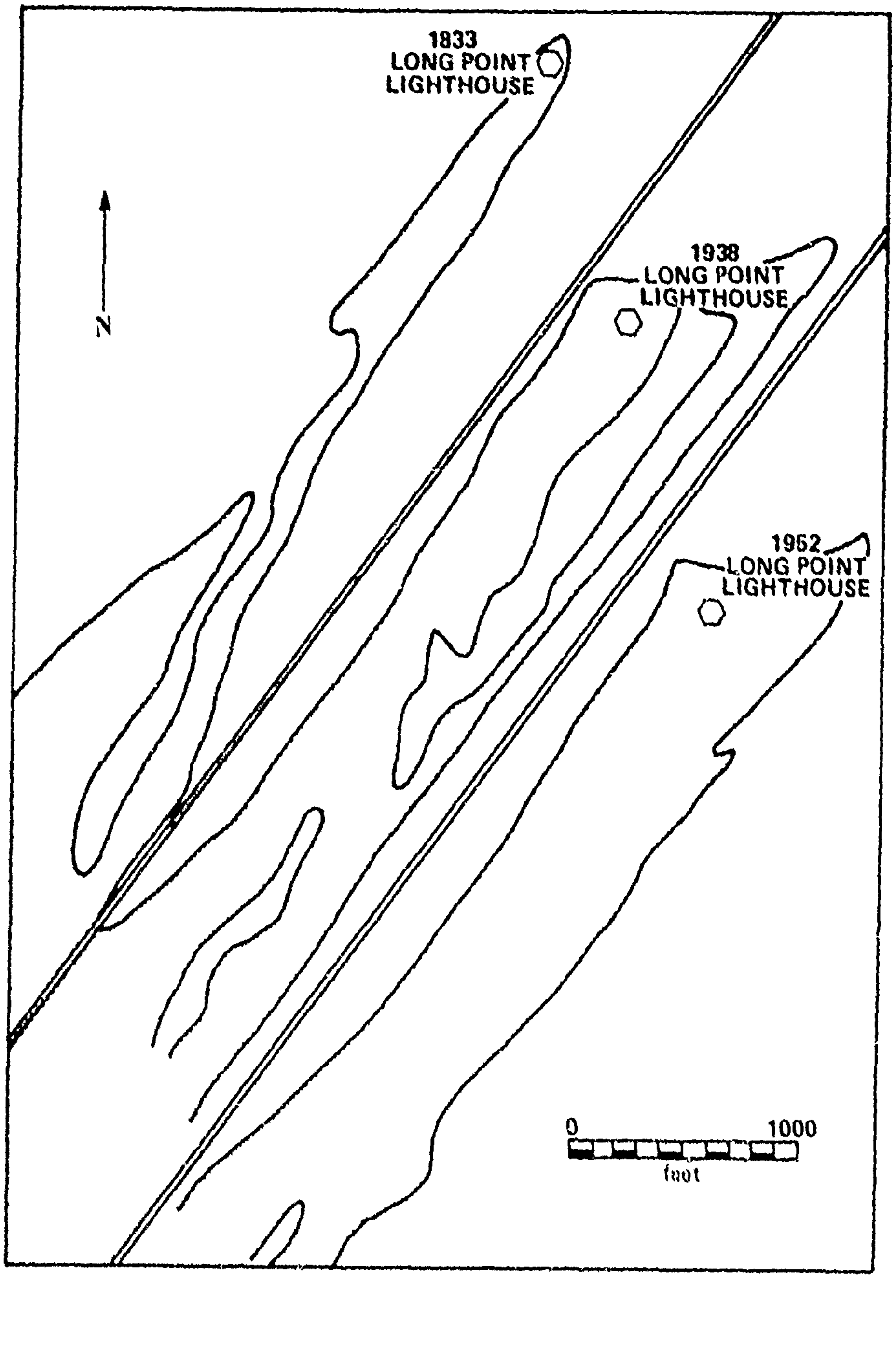


Figure 1-D3. Long Point shoreline, Provincetown

Figure 1-D4. Composite aerial photograph of Long Point, Provincetown - 1971

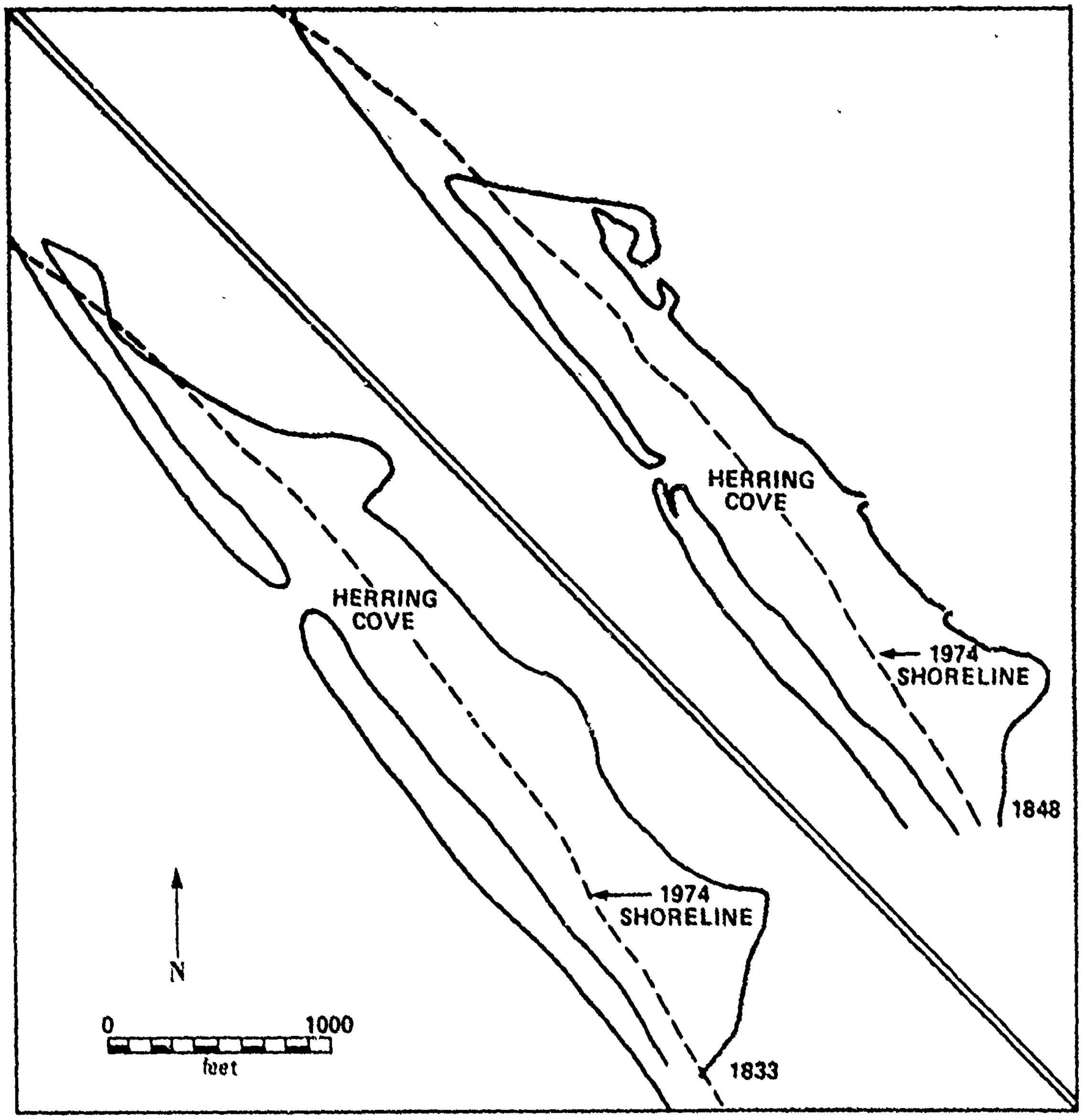


Figure 1-D5. Herring Cove, Provincetown - 1833, 1848 and 1974

Figure 1-D6. Erosion at Herring Cove Beach, Provincetown

Because Herring Cove Beach faces Cape Cod Bay, the fetch (the distance that the wind can blow over the water) is shorter than on the beaches exposed to the Atlantic. Therefore, a storm should have less effect here than on the more easterly shores, particularly when the storm is a northeaster. Herring Cove Beach has grown during northerly winds and has lost slightly under other storm conditions (Zeigler et al, 1959).

Herring Cove Beach is an area of both erosion and accretion. Sequences of several years of erosion followed by several years of accretion are common. From 1833 to 1952, the area has accreted at a slow rate as shown on the shoreline-changes maps; however, erosion has predominated during recent years.

Hatches Harbor

Once a harbor of refuge for several hundred fishermen in the 1830s, Hatches Harbor today is a shoaled and diked marsh located behind Race Point. The extent of shoaling that has occurred is shown in Figure 1-D7.

Sand blown inland from Race Point Beach has caused much of the Hatches Harbor area to become a dry plain. Sand transported by littoral drift around Race Point has formed a spit at the entrance to Hatches Harbor. As these processes continue, Hatches Harbor will eventually shoal across the inlet by the deposition of sand from the ocean while the remaining harbor and marsh fill with windblown sand to become a dry plain.

Race Point

Race Point Beach is the westernmost point on the Provincetown Hook. This beach is characterized by abrupt day-to-day change that is probably influenced by the presence of Peaked Hill Bar. Wind fetch varies from 21 nautical miles for northwest winds to 100 nautical miles for northeast winds. Race Point Beach is supplied by material eroded from the cliffs at The Highlands and transported 8 nautical miles to the northwest by longshore currents (Zeigler et al, 1959).

Historical changes in the Race Point shoreline are shown in Figure 1-D8. From 1887 to 1957, beaches along this northern coast prograded at rates from 0.5 to 5 feet per year (Shepard and Wanless, 1971). The process, however, did not involve continuous accretion. During one 3-year period (1953 to 1956), Race Point lost more material than was added and the beach alternated between periods of progradation and retrogradation (Zeigler, 1956).

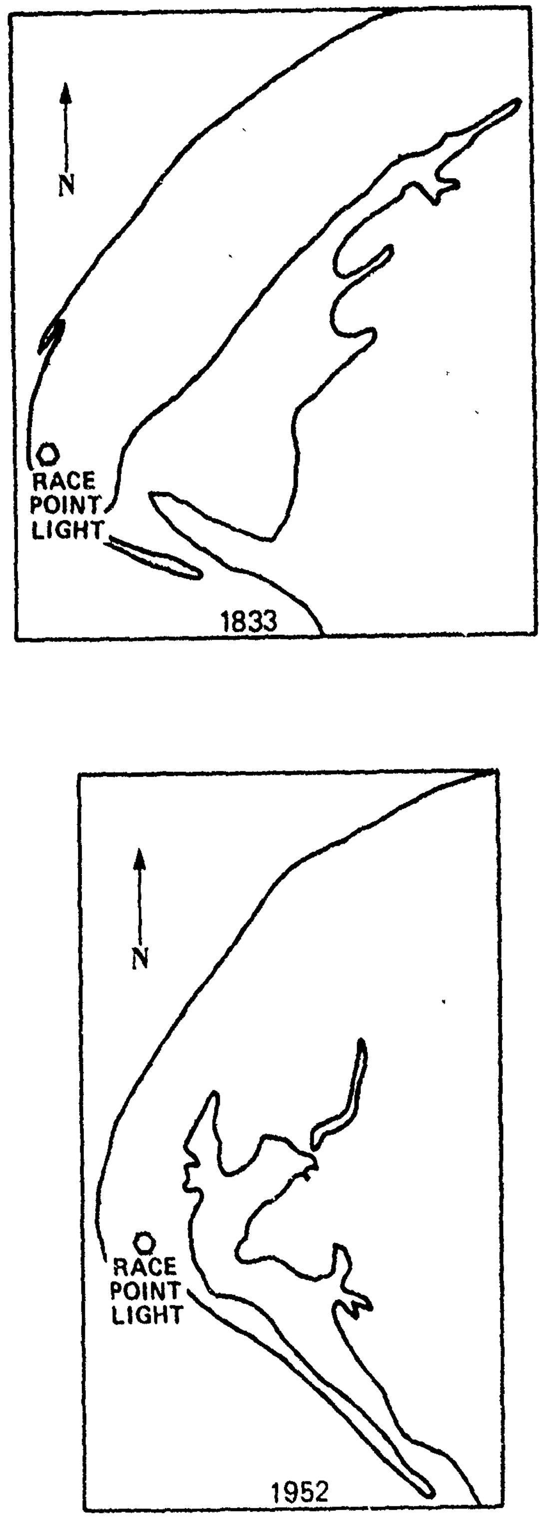


Figure 1-D7. Shoaling at Hatches Harbor, Provincetown, 1833-1952

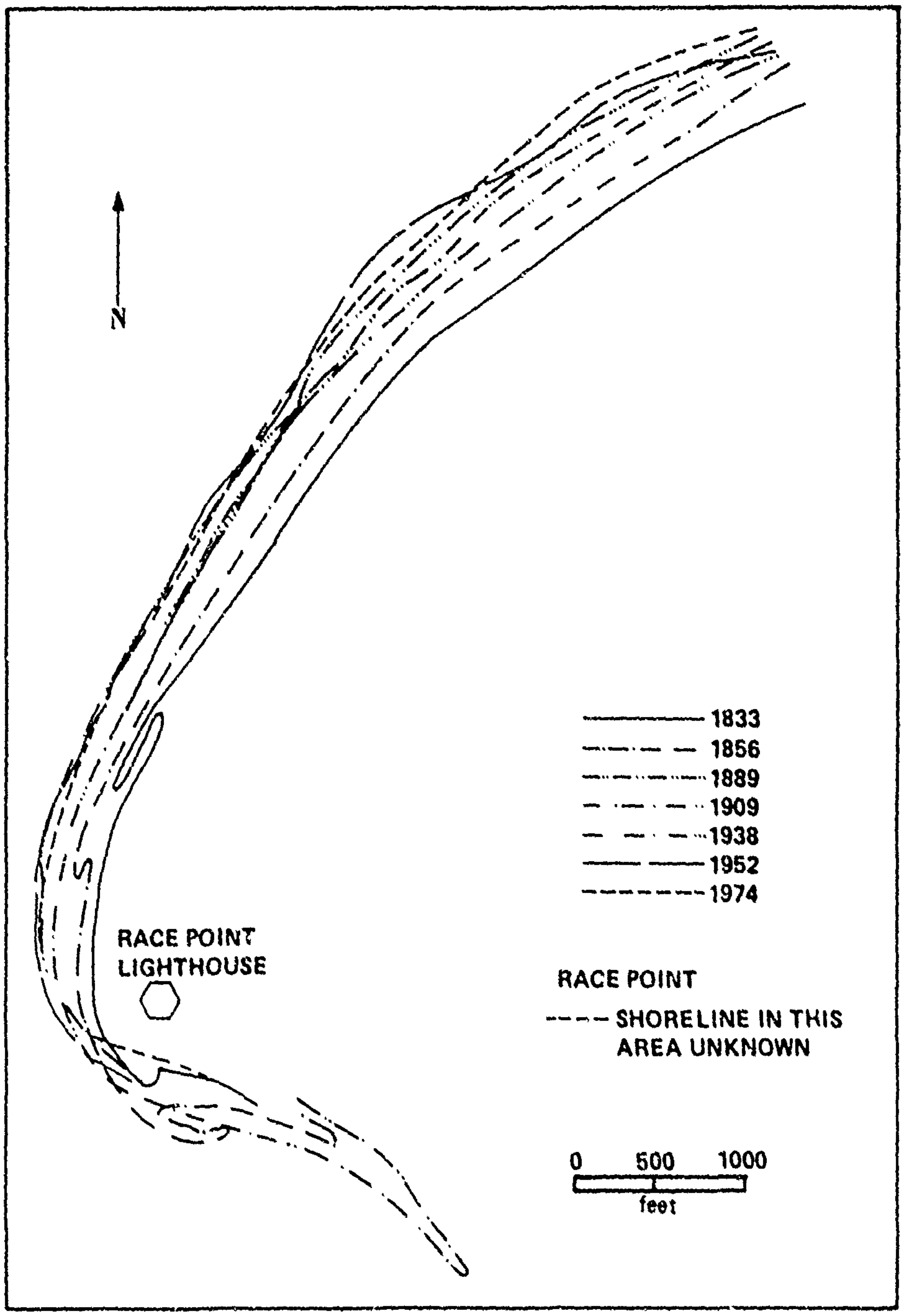


Figure 1-D8. Shoreline changes at Race Point, Provincetown 1833-1974

Investigations of storm effects on Race Point Beach showed that the beach generally gained volume under east winds and lost volume under north and northeast winds (Zeigler et al, 1959). Peaked Hill Bar, located 1,000 to 2,000 feet offshore, protects Race Point during storms. Erosion was less in this area than at either High Head or The Highlands, and longshore transport of sediment eroded from High Head and The Highlands areas is probably responsible for numerous large gains in material observed at Race Point Beach. In addition to building the shoreline, material from Race Point Beach is also blown inland where it is filling Hatches Harbor and contributing to dune building.

Head of the Meadow Beach

Head of the Meadow Beach is located in the northern part of Truro, east of Pilgrim Lake and north of High Head. At High Head, old marine scarps mark the northernmost location of glacial deposits. Waves originally attacked High Head, itself, when sea level rose to near its present height (Strahler, 1966). Sands eroded from The Highlands of Truro and carried along the shore built the Provincelands Hook beyond High Head, thus protecting the scarp from further wave attack.

Northwesterly transport of sand from the scarp at The Highlands (1.5 nautical miles south) supplies Head of the Meadow Beach. Directly off the coast, the wind has a possible fetch of 80 nautical miles. Northeasters, however, can blow across 150 nautical miles of open ocean before reaching the beach. Northwest, north, and southwest winds caused little change at High Head; as a result of an east wind, however, the beach actually gained volume. This may have been caused by more detritus arriving in the area than was being carried away (Zeigler et al, 1959).

Inspection of aerial photographs from 1938 to 1974 showed that the high-water line in this area shifted seaward and landward regularly (Gatto, 1975), a conclusion that is supported by the shoreline-change maps.

Peaked Hill Bar

Peaked Hill Bar, which begins tangent to the beach at The Highlands and extends to Race Point, is a fairly permanent longshore bar (Fisher, 1972). Head of the Meadow, High Head and Race Point beaches are located in the lee of the bar. Between Peaked Hill Bar and the beach, sand has been observed to move in a series of giant ripples that are transverse to the beach and bar. These ripples migrate along the shoreline (Zeigler and Tuttle, 1961). Peaked Hill Bar protects the beaches in its lee, particularly during storms.

Provincelands Summary

Analysis of historical charts has shown that Pilgrim Lake has lost its connection with the sea and that Long Point, has been a basically stable feature. Herring Cove no longer exists as a cove and Herring Cove Beach is presently eroding. Hatches Harbor has shoaled, due to longshore transport and windblown sand. Race Point is accreting and is strongly influenced by Peaked Hill Bar.

While this qualitative assessment demonstrates the long-term trend in shoreline changes, it can provide only a crude quantitative measure of the rate of change. Due to inconsistencies in the surveys (i.e., the length of elapsed time during the surveys, the season and stage of the tide during which the surveys were made, etc.) any erosion/accretion rates derived from these data will be subject to uncertainties of unknown magnitude. However, detailed studies of aerial photographs from 1938 to 1974 have produced values for net change in the high-water line, the total change in the high-water line, and an annual rate of change, as shown in Table 1-D1. During this interval, net erosion occurred from Long Point to Herring Cove; net accretion was noted from Race Point to the eastern end of Pilgrim Lake (Gatto, 1975).

The maximum amount of change along this section of the coast occurred at a location east of Race Point where the total change (advance and retreat) was 415 feet during the 36-year period. Table 1-D1 also shows that although 330 feet of change occurred at Race Point Coast Guard Station, the net change was only 10 feet of erosion.

The total and net changes documented in Table 1-D1 and the shoreline changes discussed in this section demonstrate the dynamic nature of the Provincelands coast. An estimate of the shoreline location 50 years from now, derived from wave refraction analysis, is presented in the section entitled "Shoreline Predictions" in Section E of this appendix.

THE MARINE SCARP - TRURO TO EASTHAM

The coast of Cape Cod from High Head in North Truro to Coast Guard Beach in Eastham consists of a nearly continuous, steep slope known as a marine scarp (Figure 1-D9). Where stream valleys have intersected the scarp, gaps are visible (Gatto, 1975). Wave erosion of thick, glacial, outwash plain deposits has produced the scarp (Fisher, 1972). For much of its length the scarp is 50 to 150 feet high (Strahler, 1966); two miles north of Newcomb Hollow Beach near the Truro-Wellfleet town line, the scarp reaches nearly 180 feet (Gatto, 1975).

The scarp, extending about 15 miles along the outer Cape shore, indicates that at one time the Cape extended farther to the east than at present (Fisher, 1972). Early investigators estimated the original extent as about 2-1/2 miles farther to the east (Davis, 1896 cited in Fisher, 1972 and as

Table 1-D1. Net changes, net annual rates of change and total amounts of change in positions of the high-water line from Long Point to Pilgrim Heights Area, 1938-1974 (After Gatto, 1975)

REFERENCE POINT	LOCATION	NET CHANGE[1] (ft)	NET ANNUAL RATE OF CHANGE[2] (ft/yr)	TOTAL AMOUNT OF CHANGE[3] (ft)
1	Long Point	-252.0	-7.0	-
3	Wood End	-179.3	-5.0	+189.1
4	Beginning of Wood End-Long Point Spit	+ 69.0	+1.9	-
5	South End of Herring Cove Beach	-119.6	-3.3	+131.7
6	North End of Herring Cove Beach	- 14.7	-0.4	+55.7
9	Race Point Lighthouse	-118.7	-3.3	+171.0
10	Race Point Beach	+124.5	+3.5	+165.0
12	Race Point Coast Guard Station	- 10.2	-0.3	+330.2
13	Between Race Point Coast	+321.4	+8.9	+414.8
14	Guard Station and Pilgrim	+223.6	+6.2	+304.8
18	Heights Area	+102.9	+2.9	+240.6
20	Western End of Pilgrim Heights Area	- 39.4	-1.1	+189.0
24	Eastern End of Pilgrim Heights Area	+ 97.4	+2.7	+321.6

[1]Difference between position in 1938 and 1974.

[2]Net change divided by 35.9 years.

[3]Summation of total changes for 1938-1952, 1952-1971, and 1971-1974 (Table 5 in Gatto, 1975) whether accretion (+) or erosion (-).

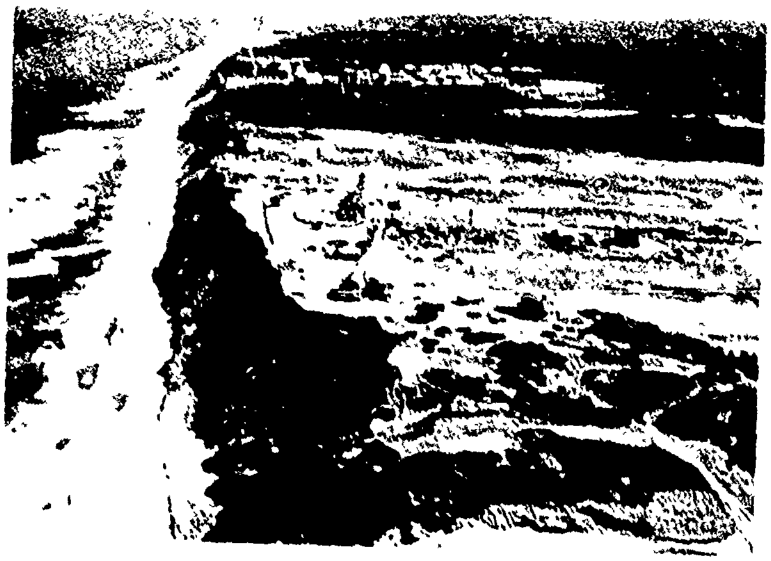


Figure 1-D9. Marine scarp of Cape Cod

between one-half mile and 4 miles (Shaler, 1897 cited in Fisher, 1972). The original irregular shoreline has been eroded by waves to its present gently curving configuration.

Two sources of evidence cited by Strahler (1966) that suggest a more easterly shoreline are the historical erosion rates and the valleys of outer Cape Cod. It is very difficult to project the historical shoreline from the recent erosion rates because several factors, particularly the erosion rate and rate of sea-level rise, may have changed. These calculations place the coastline about 2 miles to the east, 3,500 years ago, the time when the sea probably neared its present level. The valleys, which seem to have been formed by water coming from the South Channel lobe to the east, are further evidence that the probable position of the Cape Cod shoreline was once farther to the east (Strahler, 1966).

Due to the presence of structures and government installations on this section of coast, detailed historical records of shoreline changes are available at several locations including Highland Light, Ballston Beach, Marconi Station, and Nauset Light. Highland Light (U.S. Coast Guard), North Truro Radar Base (U.S. Air Force), Marconi Station Area (National Park Service) and Nauset Light (U.S. Coast Guard) are located on the bluff; beaches along the base of the scarp include Highland, Longnook, Ballston, Newcomb Hollow, Cahoon Hollow, LeCount Hollow, Marconi, and Nauset Light beaches. The scarp occurs again on the outer coast at Nauset Heights, south of Nauset Harbor inlet.

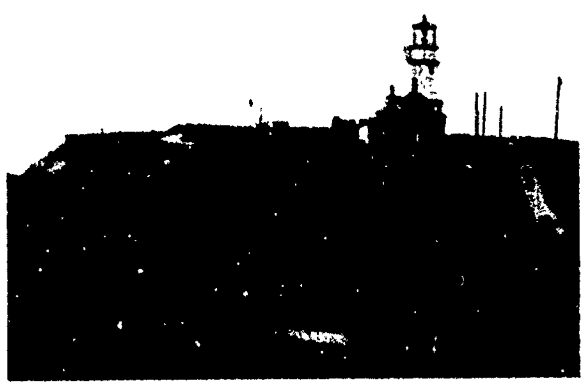
Highland Light

Highland Light (Figure 1-D10), also known as Cape Cod Light, was originally constructed in 1797 on a 10-acre tract of land. Today, only 2.5 of the original 10 acres remain; the rest has been lost to erosion (Chamberlain, 1964). The presence of clay at Highland Light causes large volumes of material to fall onto the beach. Occasionally, one area will experience little erosion for several years while adjacent land may lose 50 to 60 feet during a single storm.

Large losses of material in a single incident are well-documented at Highland Light. Thoreau, who included Highland Light in an erosion study he compiled on Cape Cod, mentions that during one day in 1848 over 60 feet of the front yard disappeared before the observer's eyes. In a similar incident during the winter of 1976-77, a section over 60 feet deep and close to 200 feet wide dropped away while the adjacent property received minimal damage.

Large parcels of land have disappeared in minutes during storms. When the sea attacks the bluff, the clay underlying the topsoil becomes saturated

The scarp at Highland Light, North Truro



Highland Light, North Truro

Figure 1-D10. Highland Light, North Truro

and large slips or slides, involving the clay, fall into the sea. Therefore, the erosion rate at Highland Light is very difficult to predict. This is not true of the majority of the outer Cape, which is constructed of unconsolidated sand material.

Highland Light Beach is partially protected by the presence of a nearshore bar (Peaked Hill Bar) that absorbs storm energy (Zeigler et al, 1959). Storms that damage the outer bar make the beaches behind the breach more vulnerable; wasting of the beaches generally occurs opposite cuts in the bar (Zeigler et al, 1959). Erosion of the beach leads to wave attack directly on the marine scarp, with resultant undermining of the bank.

In their analysis of the effect of storms on beaches, Zeigler et al (1959) found that the toe of the scarp might be untouched by many of the storms that eroded the beaches. However, when storm waves did reach the scarp (January and May, 1956), the scarp base was eroded 20 feet, leaving vertical cuts 5 and 14 feet high at the locations studied. Material sliding down the scarp face filled the cuts by May 1956. Between October 1953 and January 1958, the scarp toe at Highland Light retreated 4 feet and the top of the scarp retreated 4-1/2 feet (Zeigler et al, 1959). Historical changes at Highland Light are shown in Figure 1-D11.

Pamet River /Ballston Beach

Ballston Beach is located on the eastern shore of Cape Cod in Truro at the head of the Pamet River, which is separated from the beach by a narrow sand dune. When the Pamet River Life Saving Station was built at Ballston Beach in 1872, it stood several hundred feet back from the high-water mark. By 1920, water was reaching the station's foundation at high tide. The high-water mark is now located 325 feet inland from its location when the station was constructed.

A major shoreline change anticipated at this site is the breakthrough of the ocean into the Pamet River valley. Waves have overtopped the barrier dunes in the past, and residents fear that a breakthrough would alter the freshwater marsh and threaten the groundwater in the area.

The general trend in this area has been erosion, as shown in the shoreline-changes maps (Figure 1-D12) and studies of aerial photographs (Gatto, 1975).

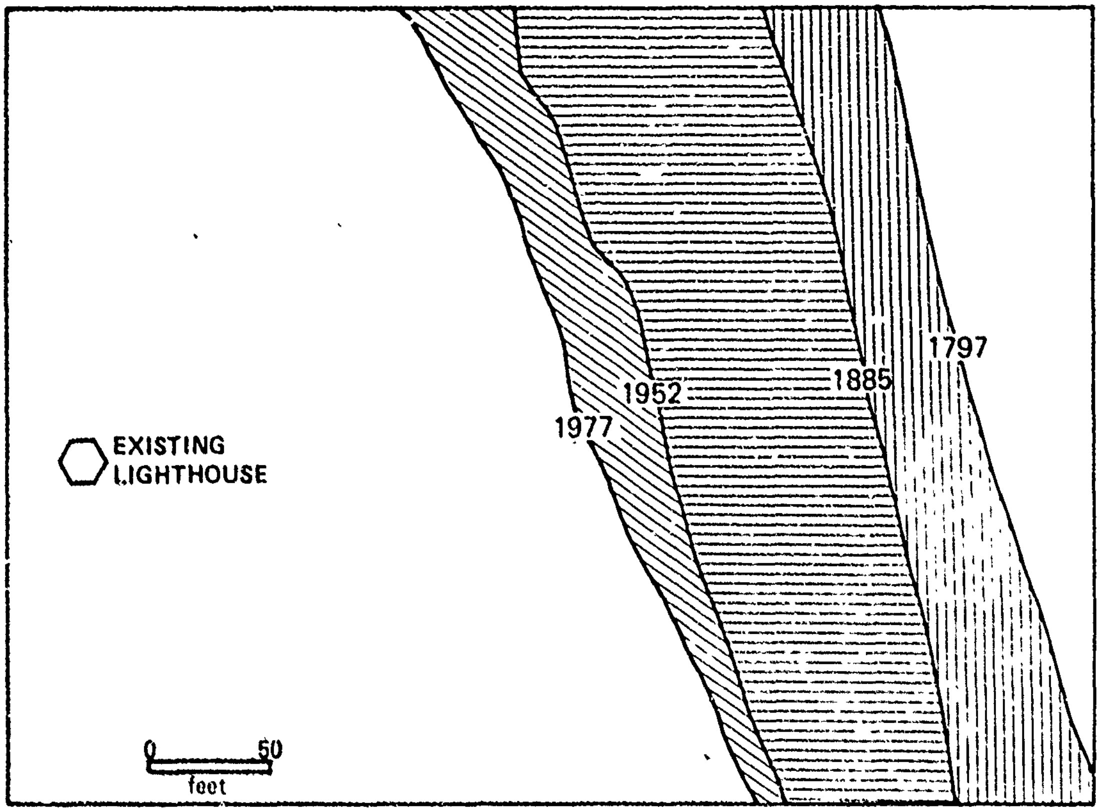


Figure 1-D11. Historical changes at Highland Light

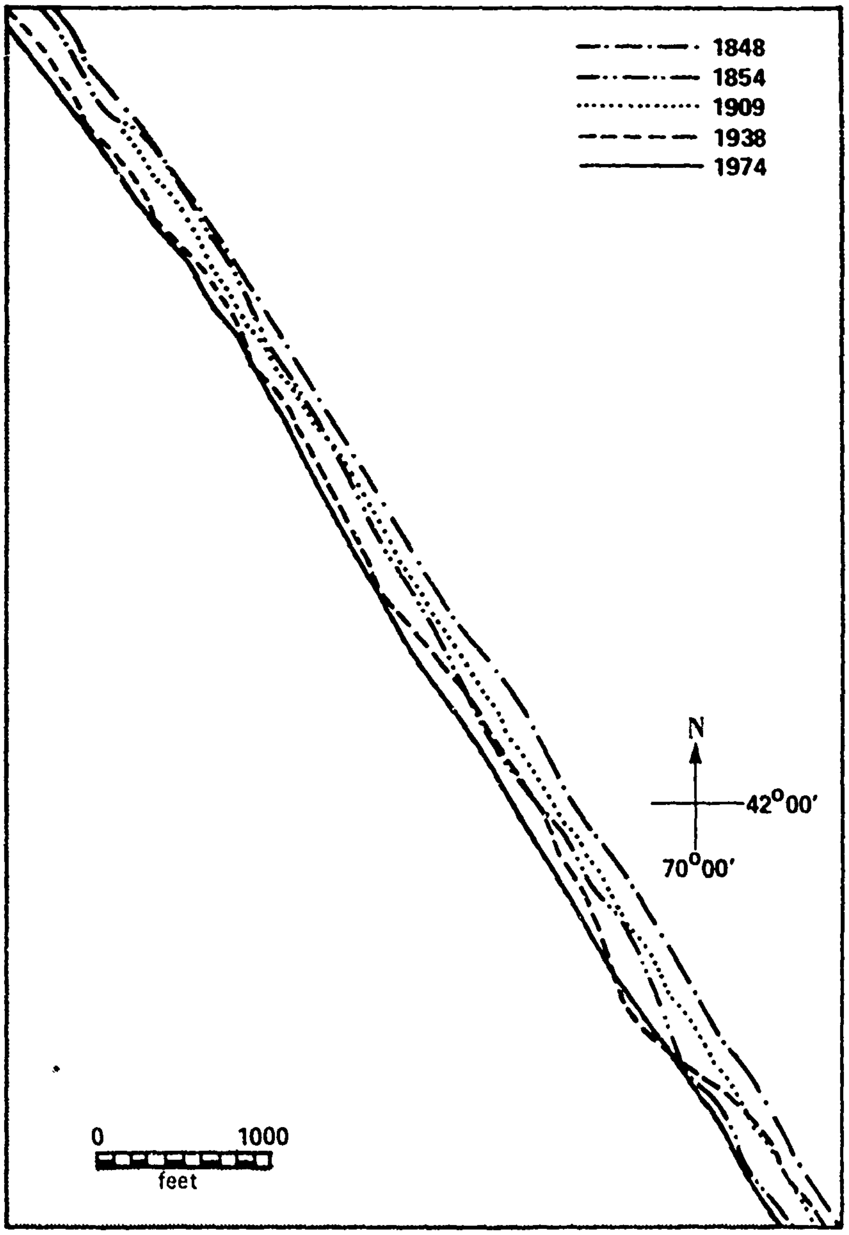


Figure 1-D12. Shoreline changes near Ballston Beach, Truro

Marconi Station

Marconi Station was established at Wellfleet in 1900 as a permanent radio station for trans-Atlantic communications. Between 1902 and 1972, the scarp at Marconi Station eroded 170 feet and the two outer concrete bases for the radio towers fell to the beach (Fisher, 1972).

The sea has not been responsible for all the shoreline changes near this location. The development of Camp Wellfleet (U.S. Army) between 1938 and 1952 damaged much of the vegetative ground cover, both near the beach and several hundred feet west of the scarp edge (Figure 1-D13). Some of the paths and areas barren in 1952 had recovered by 1971, but much of the damage was still noticeable.

Nauset Light

Three brick lighthouses known as the "Three Sisters of Nauset" were constructed at this location in 1839 (Fisher, 1972). Due to erosion of the scarp, the three lighthouses fell into the sea in 1892; they were replaced by three wooden lighthouses. In 1911, a single wooden lighthouse was built and the existing lighthouse was moved to its present location from Chatham in 1923. Erosion at this site is detailed in Figure 1-D14, which shows the position of the original lighthouses and the present lighthouse. Erosion at the present lighthouse is shown in Figure 1-D15.

Coast Guard Beach

Coast Guard Beach extends south from the scarp onto a narrow sand spit. Critical erosion problems on the spit are discussed in the section on Migrating Inlets and Spits. Erosion of the scarp at Coast Guard Beach had been undermining the parking area (Figure 1-D16) that was located at the edge of the scarp above the beach (Fisher, 1972). Winter storms are responsible for much of the erosion here (Fisher, 1972) and the winter of 1977-78 proved no exception. During a northeaster that paralyzed southern New England with snow, storm waves destroyed the parking lot, bathhouse, and Coast Guard Beach (Figure 1-D17).

Figure 1-D13. Aerial photograph of Marconi Station site, Wellfleet, November 1938

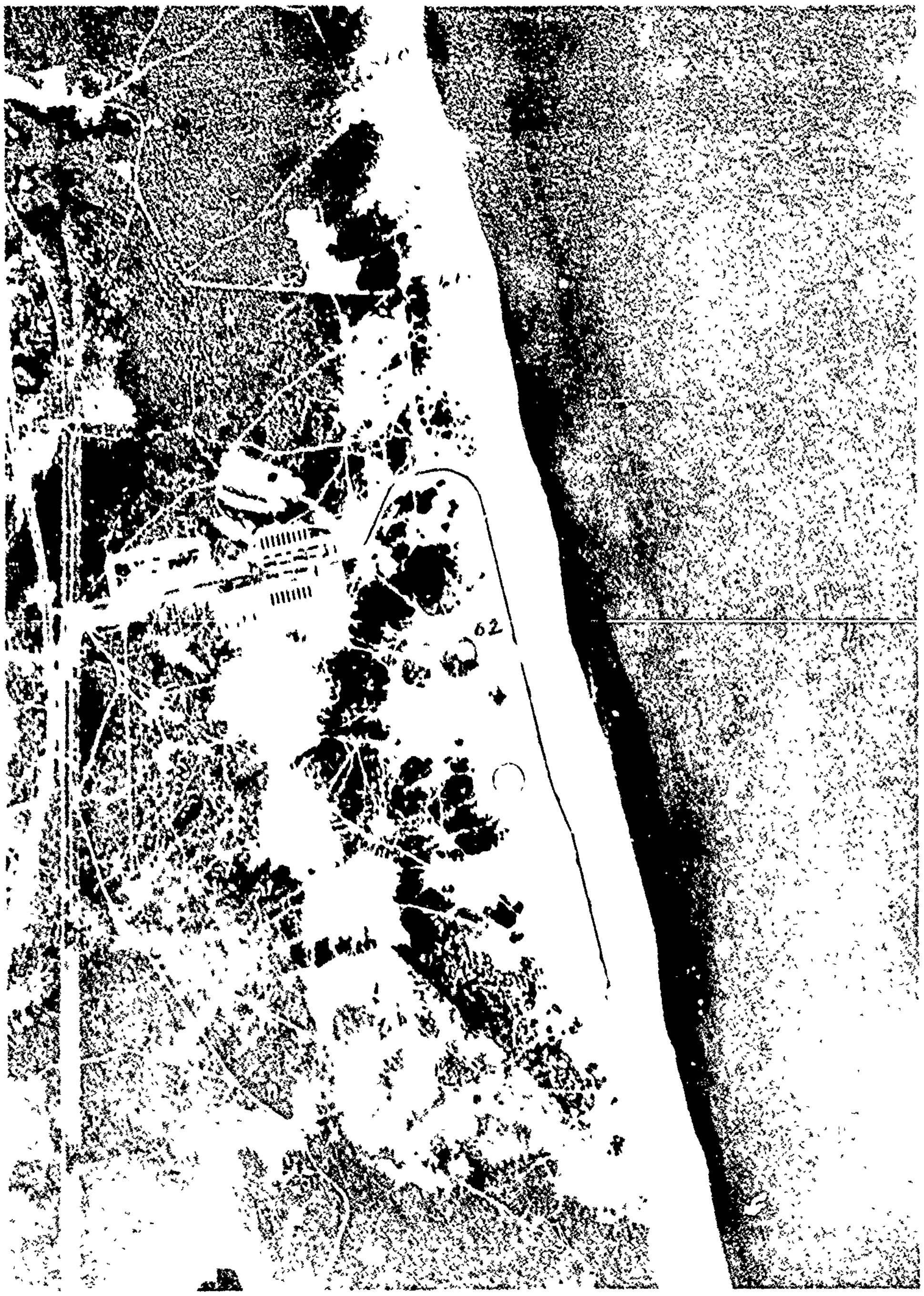


Figure 1-D13. Aerial photograph of Marconi Station site, Wellfleet, July 1952

Figure 1-D13. Aerial photograph of Marconi Station site, August 1971

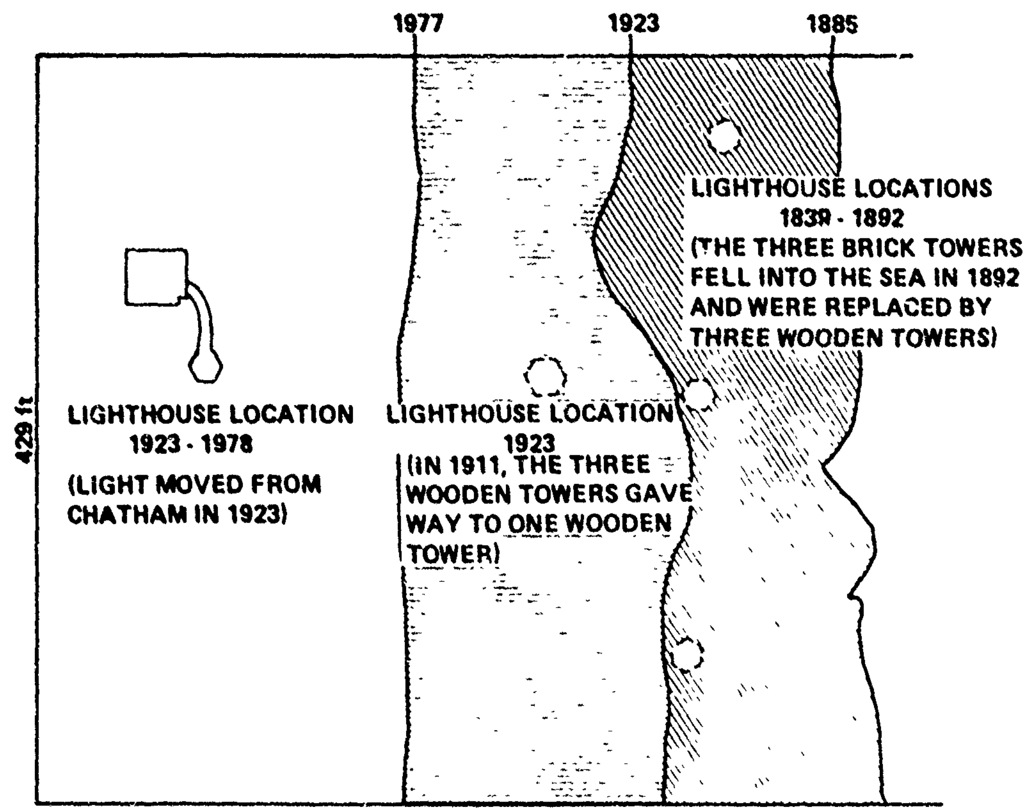
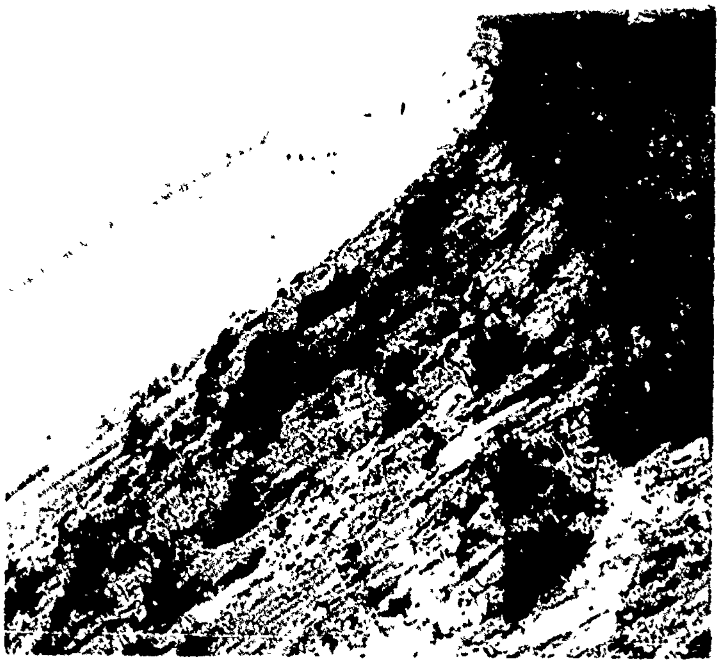


Figure 1-D14. Sketch showing erosion at Nauset Light, Eastham



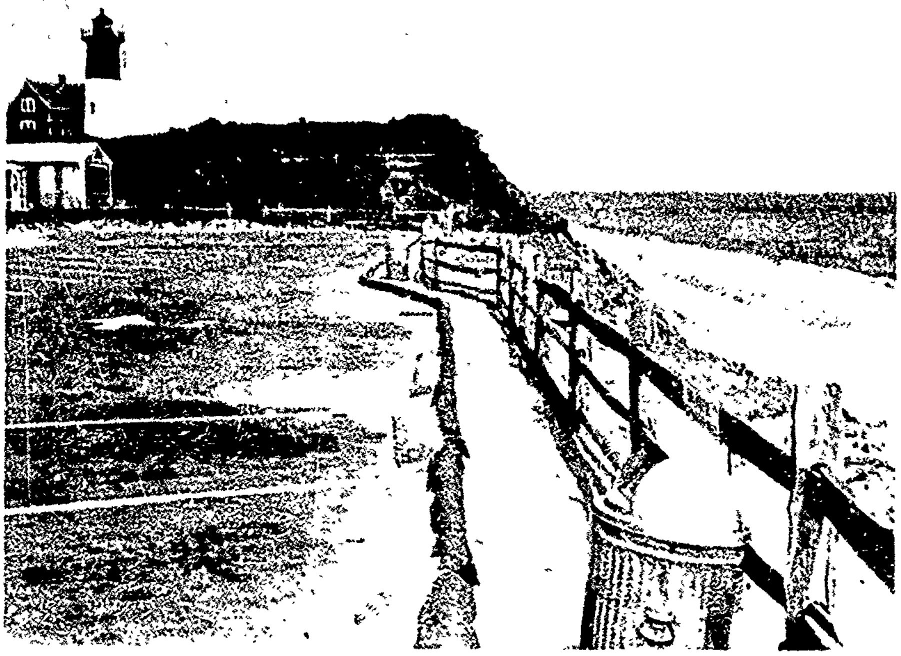
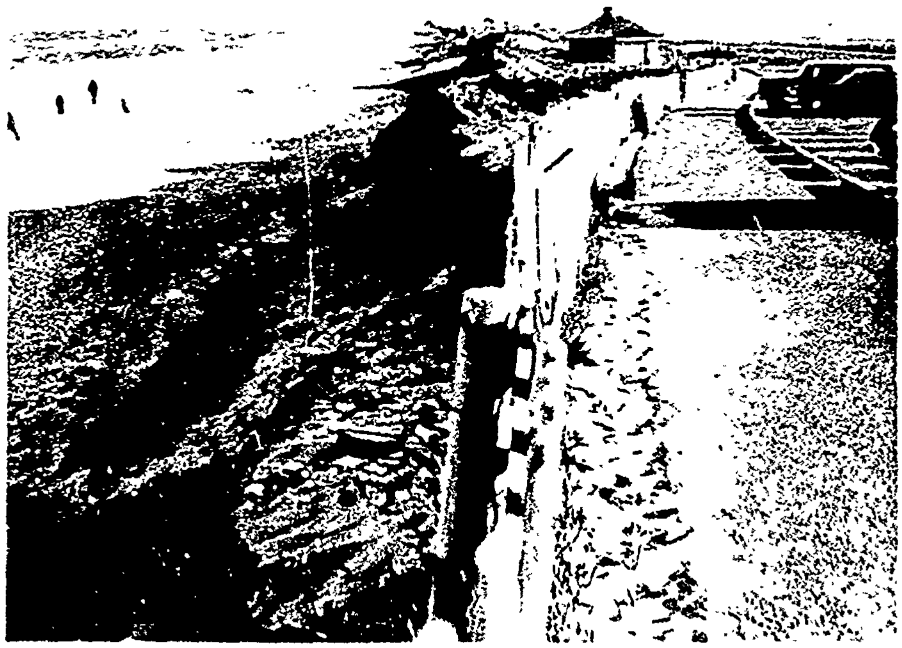


Figure 1-D15. Photographs showing erosion at Nauset Light, Eastham



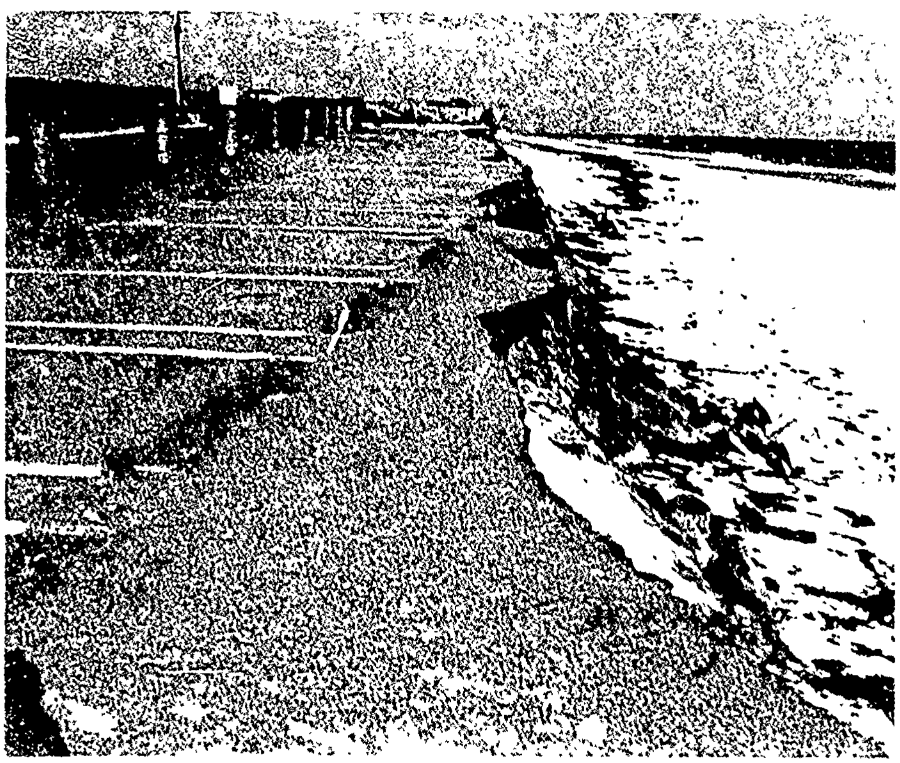


Figure 1-D16. Erosion of the parking area at Coast Guard Beach

Figure 1-D17. Damage at Coast Guard Beach, Winter 1977-78

Recession of the Scarp

Recession of the scarp on eastern Cape Cod is caused by erosion of the glacial material on the face of the scarp. Two major factors contributing to the erosion are wave attack on the base of the scarp and erosion of the scarp face by rain and runoff. Rain causes deposition of small fans of clay and gravel at the foot of the scarp (Zeigler, 1960). This material can then be carried out to sea by waves. Whether waves are able to reach the scarp or the material deposited at the scarp base depends on the condition of the beach. A wide beach protects the scarp base from waves and when the beach is wasted, waves attack the scarp directly (Zeigler et al, 1959).

Marindin of the U.S. Coast and Geodetic Survey conducted a careful survey of the Cape Cod coast from 1887 to 1889. By comparing his survey results with charts for 1848, 1856, and 1868, he determined the average erosion rate to be 3.2 feet per year for the section of coast from Highland Light to Nauset Light (Zeigler et al, 1964). His profile lines were reoccupied by Zeigler and his associates in 1958 and 1959. Their results showed that the main scarp was being eroded at an average rate of 2.6 feet per year (Zeigler et al, 1964). Erosion rates are not uniform along the coast. In his analysis of aerial photographs, Gatto (1975) found that net rates of change from 1938 to 1974 varied from 0.1 to 7.3 feet per year, with the greatest net changes occurring near Highland Beach and north of Nauset Beach. His results for the coastal scarp are given in Table 1-D2.

MIGRATING INLETS AND SPITS

Introduction

From the southern end of Coast Guard Beach, Eastham, to the tip of Nauset Beach, Chatham, Cape Cod's eastern coast consists of a series of barrier beaches, spits and inlets (Figure 1-D18). Coast Guard Beach is located at the northern end of a spit that separates Nauset Harbor and Nauset Bay from the Atlantic Ocean. An inlet separates this northern spit from the southern spit in the Nauset Harbor complex; the southern spit extends north from Nauset Heights, where a marine scarp is visible. South of Nauset Heights, Nauset Beach extends southward in the towns of Orleans and Chatham, finally terminating at the entrance to Chatham Harbor and Pleasant Bay. South of Chatham Harbor, Monomoy Island reaches out into Nantucket Sound.

Material eroded from the marine scarp to the north and carried south by longshore currents has built Nauset Beach and Monomoy Island. Continued erosion, transport, and wave and tidal action cause the spits to increase and decrease in length, to migrate into the marshes behind them, and to change shape. Dramatic growth and retreat in short periods of time have been recorded. Migration of the shoreline westward has generally occurred at a slower rate. The rate at which the barrier beaches are retreating is the same rate as the erosion of the scarps.

Table 1-D2. Net changes, net annual rates of change and total amounts of change in positions of the high-water line from Highland Beach, Truro, to Coast Guard Beach, Eastham, 1938-1974 (After Gatto, 1975)

REFERENCE POINT	LOCATION	NET CHANGE[1] (ft)	NET ANNUAL RATE OF CHANGE[2] (ft/yr)	TOTAL AMOUNT OF CHANGE[3] (ft)
34	Highland Beach	-189.1	-5.3	+247.1
35	North of Highland Light	-103.9	-2.9	+178.4
36	Highland Light	-130.2	-3.6	+411.8
37	North Truro Air Force Station	+ 12.2	+0.3	+80.0
39	Longnook Beach	+ 39.4	+1.1	+225.9
40	North of Ballston Beach	- 73.3	-2.0	+227.7
41	Ballston Beach	- 29.9	-0.8	+34.2
42		- 6.8	-0.2	+130.3
43	South of Pamet River	-157.6	-4.4	+250.9
44		-116.0	-3.2	-116.0
49	Horseleech Pond	+ 2[illegible].7	+0.8	+307.5
50	Newcomb Hollow Beach	- 94.7	-2.6	- 94.7
51	South of Newcomb Hollow Beach	+ 24.4	+0.7	+134.0
58	LeCount Hollow Beach	- 20.3	-0.6	+124.1
59		+ 16.3	+0.5	+109.8
61	Near Marconi Beach	- 24.2	-0.7	+179.5
65	Near Wellfleet-Eastham Town Line	- 65.4	-1.8	+389.0
67		-135.7	-3.8	+207.6

[1]Difference between position in 1938 and 1974.

[2]Net Change divided by 35.9 years.

[3]Summation of total changes for 1938-1952, 1952-1971, and 1971-1974 (Table 5 in Gatto, 1975) whether accretion (+) or erosion (-); - in this column indicates total changes were always erosion.

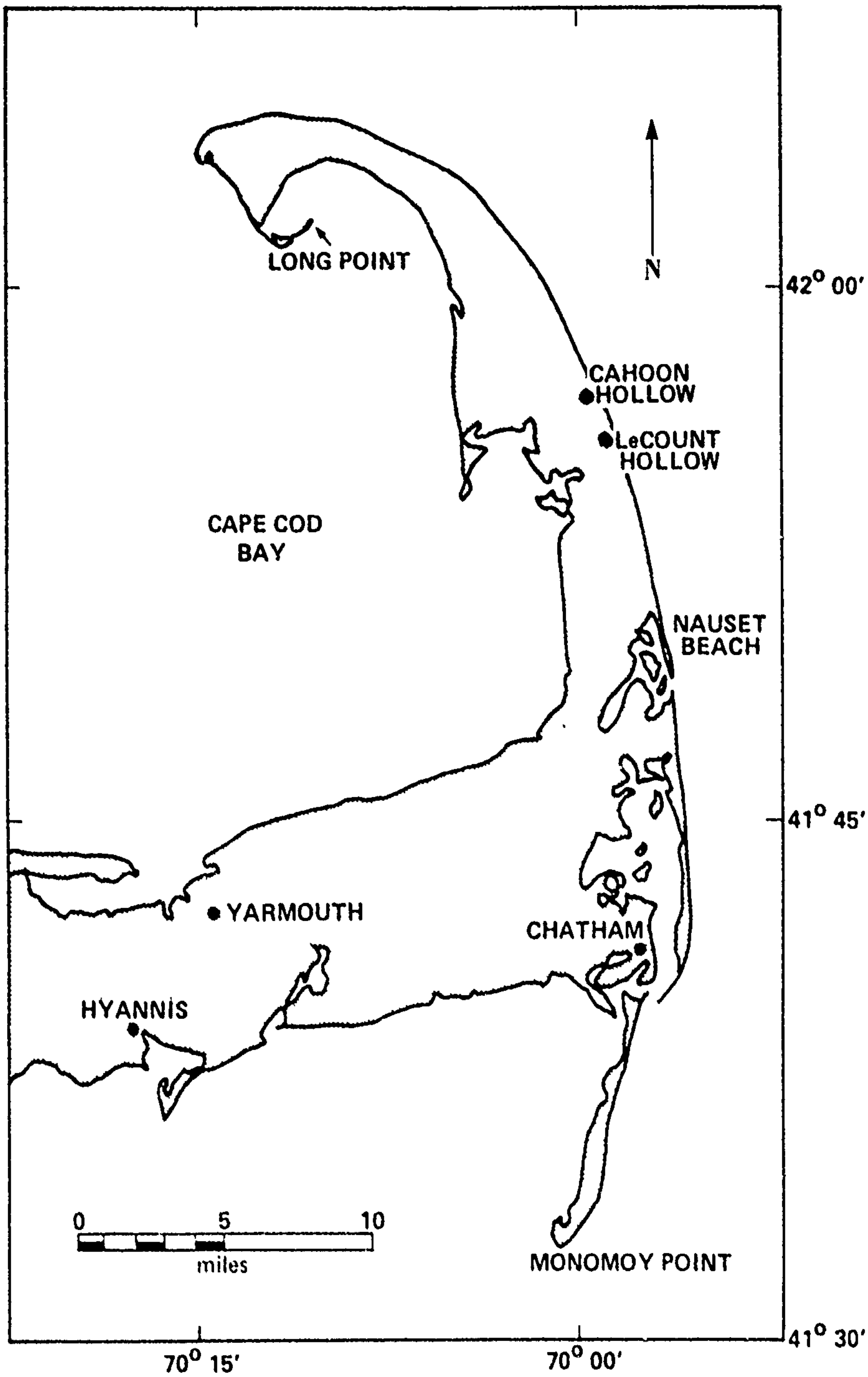


Figure 1-D18. Map of Cape Cod showing spits and inlets south of Nauset Beach (After Gatto, 1975)

Nauset Harbor Inlet

Erosion of the scarp north of Coast Guard Beach and the southerly transport of eroded material have formed sand spits that separate Nauset Harbor from the Atlantic Ocean. Communication between the two bodies of water is maintained through a small, migrating inlet (Figure 1-D19). The spits, offshore bars and inlet location are constantly changing and drastic changes have occurred in short time spans.

From at least 1856 until 1940, the inlet to Nauset Harbor was located at Nauset Heights, as shown in the early charts and the 1938 photograph (Figures 1-D20 and 1-D21). In 1941, however, the inlet moved a mile to the north when a spit grew north from Nauset Heights against the littoral drift (Zeigler, 1960). Growth of the southern spit at the inlet to Nauset Harbor is evident from the 1952, 1971 and 1974 photographs (Figure 1-D21).

Such radical changes in Nauset's spits are not uncommon. In 1957, the spits disintegrated, a new breakthrough was formed and the inlet became complex. The original southern spit length of 4,050 feet on 21 October 1957 was reduced to 1,850 feet by 10 April 1958 (Zeigler, 1960). Between 1967 and 1977 the southern spit grew from 2,680 feet to 5,880 feet. Northern migration of the inlet during this period destroyed a section of the sand fence experiment (see Section E "Inhibiting Erosion") forcing the site to be abandoned and the experiment to be relocated to the southern spit.

The situation is further complicated by the westward migration of the northern spit as it encroaches on the salt marshes behind it. This is also visible in the aerial photos. In 1938, the marshy island was distinct from the northern spit that separated it from the ocean. By 1952, part of the northern sand spit had merged with the marsh, and the spit no longer protected the marsh Shepard and Wanless, 1971). By 1971, the spit had extended south and incorporated the marsh.

Because no serious bending of the spit was observed by Zeigler and his associates, they presumed that the spit must be retreating at the same rate as the marine scarp, approximately 3 feet per year (Zeigler et al, 1964).

Nauset Beach From Nauset Heights to Monomoy

Nauset Beach continues south of the Nauset Harbor area and extends to Chatham Harbor, protecting Pleasant and Little Pleasant Bays, Chatham Harbor and several islands from the open sea. Material transported southward from the Cape's marine scarp has formed the sandy spit that extends about 8 miles south from Nauset Heights. Waves from the northeast are largely responsible for the longshore transport (Strahler, 1966).

Figure 1-D19. Photograph of Nauset Harbor Inlet (late 1960s)

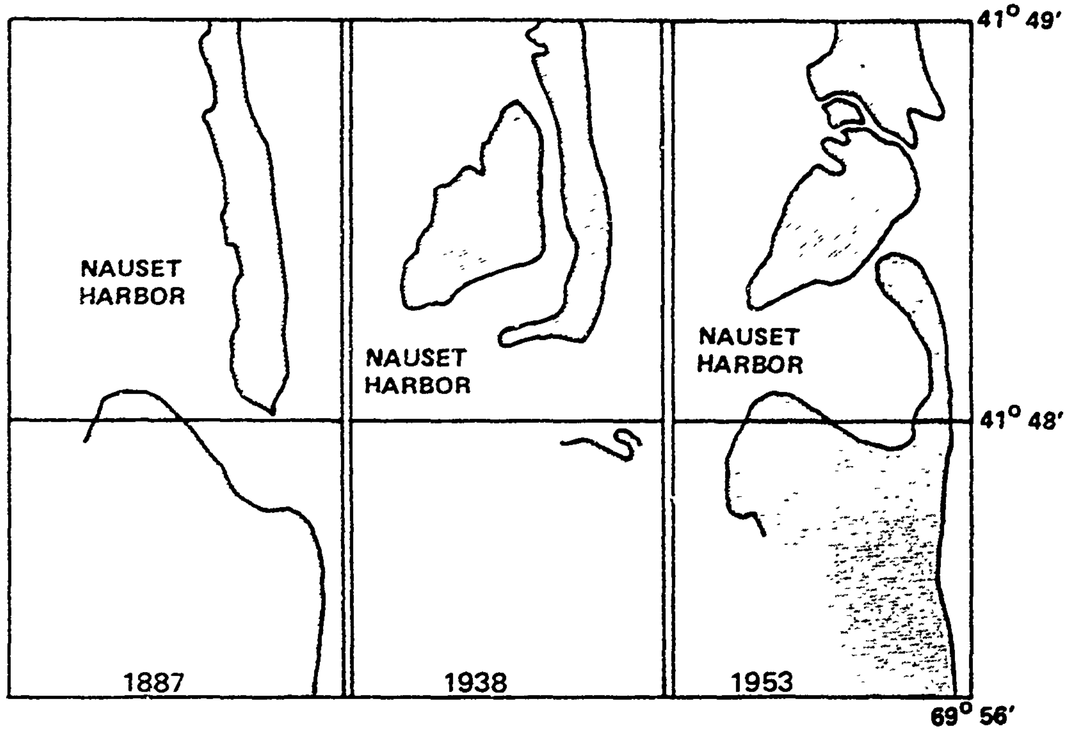


Figure 1-D20. Shoreline changes at Nauset Harbor Inlet, 1887-1953 (After Zeigler, 1956)

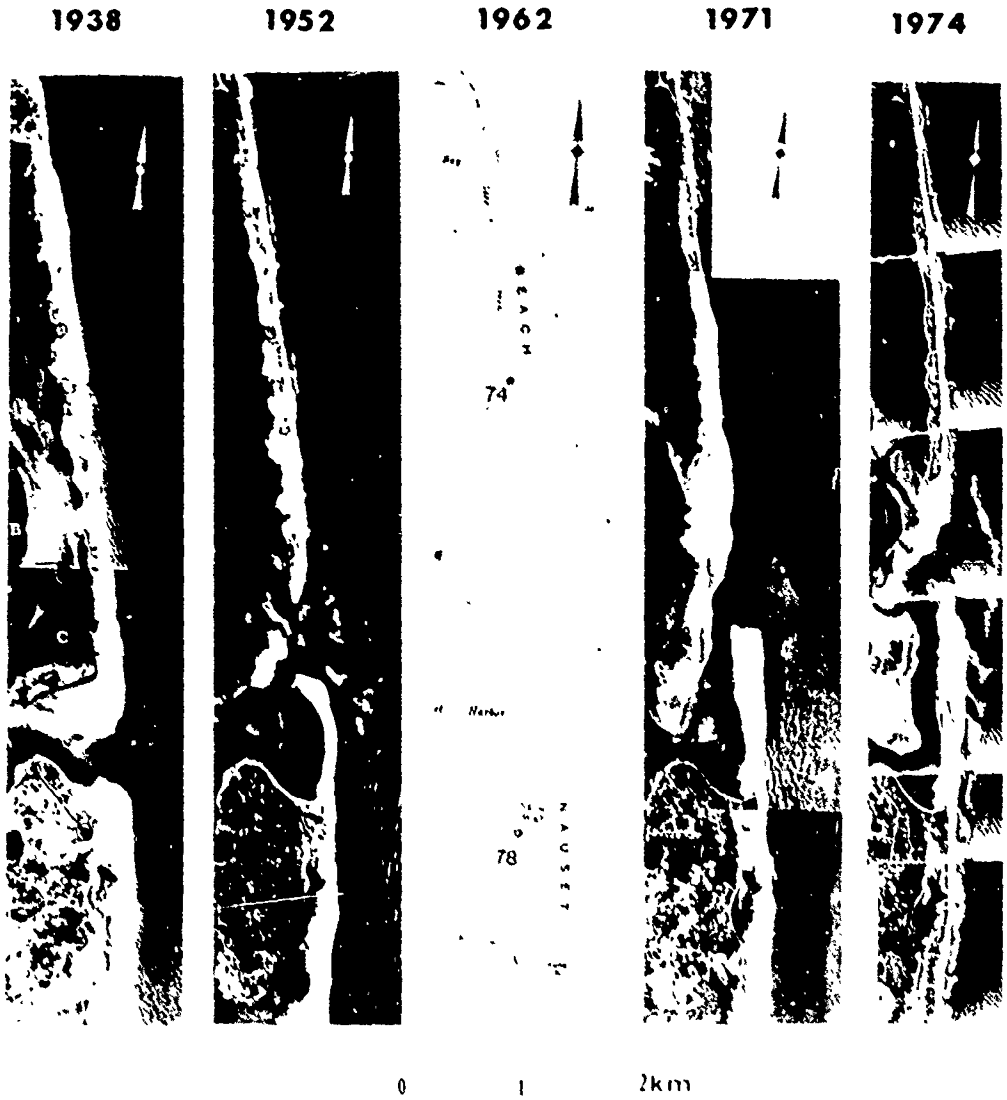


Figure 1-D21. Shoreline changes at Nauset Harbor Inlet, 1938-1974 (After Gatto, 1975)

The northern portion of the spit is covered by 10- to 15-foot high dunes. Because the southern end of Nauset was formed recently, it is low in elevation and large sand dunes have not yet developed in this area (U.S. Army Corps of Engineers, 1968).

The southern tip of Nauset Beach defines the inlet to Chatham Harbor and Pleasant Bay. The location of the inlet has changed radically during recorded history. Detailed studies of Monomoy Island and the tip of Nauset Beach (Goldsmith, 1972) have led to the identification of two and possibly three cycles of large-scale inlet migration. The most recent cycle began in 1846 when the inlet was approximately at its 1971 location. In 1846, a breach was formed in Nauset Spit creating a new inlet that is shown in the charts for 1872 and 1887 (Figure 1-D22). Old Harbor Life Saving Station was constructed at the terminus of Nauset Spit in 1897. Its name refers to the inlet that existed at that time. Nauset Spit grew about 6 miles southward between 1846 and 1971, forcing the inlet to be moved south as well (Goldsmith, 1972 cited in Hayes, 1972).

Between 1938 and 1971, deposition predominated at the tip of Nauset Spit (Figure 1-D23). This trend had reversed by 1974 and the tip had been eroded and migrated northwestward nearly one-half mile.

Nauset Beach is gradually encroaching on the bay and marshes in its lee. The spit is being driven westward into Pleasant Bay at approximately 3 feet per year as material is blown or carried through the washovers (U.S. Army Corps of Engineers, 1968).

Monomoy Island

Although Monomoy is not included in the limits of the study area, it is an integral part of the outer Cape complex of barrier beaches and spits. Like Nauset Beach, Monomoy (presently an island extending 8 miles south into Nantucket Sound) has been built by the longshore transport of eroded materials. Sand eroded from the marine scarps on the outer Cape is carried south by longshore currents, particularly during northeast storms, to be deposited on Monomoy (Strahler, 1966).

Dramatic changes have occurred in Monomoy Island since 1846 (Figure 1-D24). The chart for 1846 shows a poorly defined group of islands in the Nauset Beach-Monomoy area. By 1868, Nauset Beach and Monomoy are shown as a continuous spit located east of the mainland of Chatham. Nauset Beach terminated near Morris Island in 1886, and the chart gives little information about Monomoy at that time. Nauset Beach, however, underwent a significant migration to the west. By 1899, Nauset Beach and Monomoy had rejoined, a configuration that is also apparent in the 1902 chart. By 1931, Monomoy had migrated west where it became attached to Morris Island and the mainland of Chatham. Winter storms in 1957-58 separated Monomoy from Morris Island.

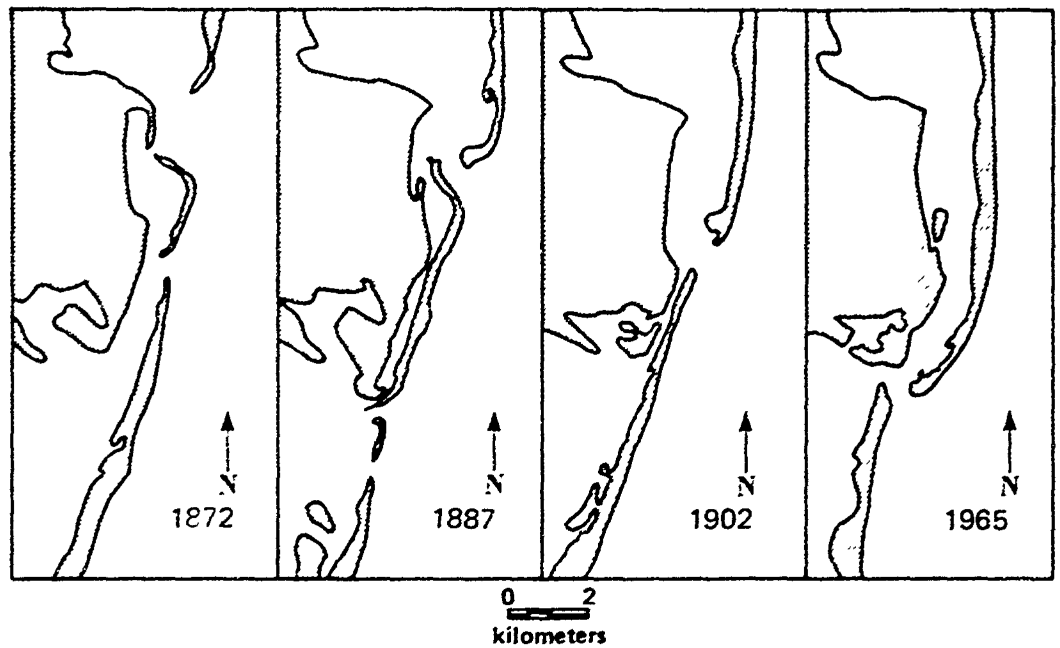


Figure 1-D22. Migration of the tip of Nauset Beach, Chatham, and the Inlet to Chatham Harbor and Pleasant Bay (After Hayes, 1972)

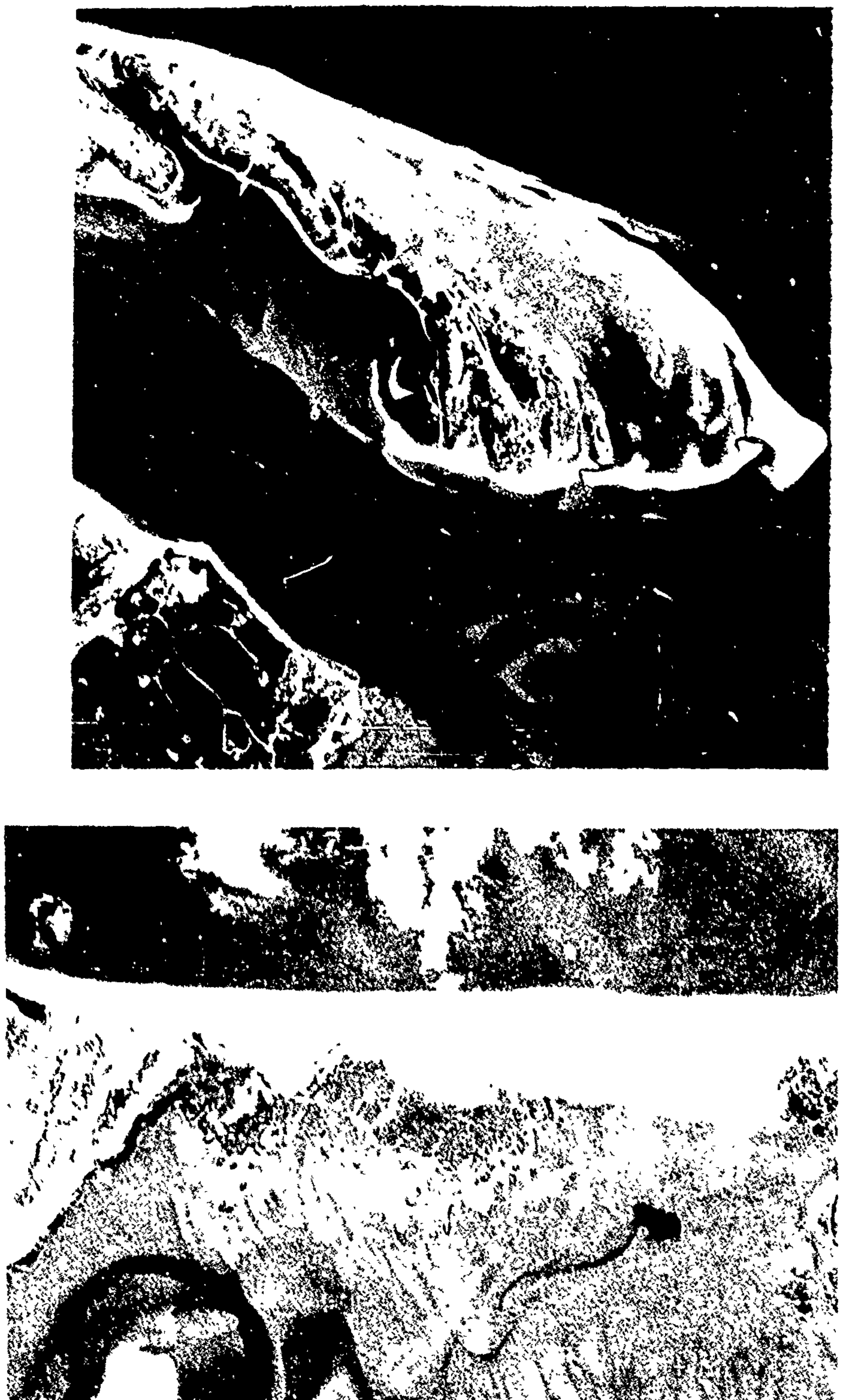
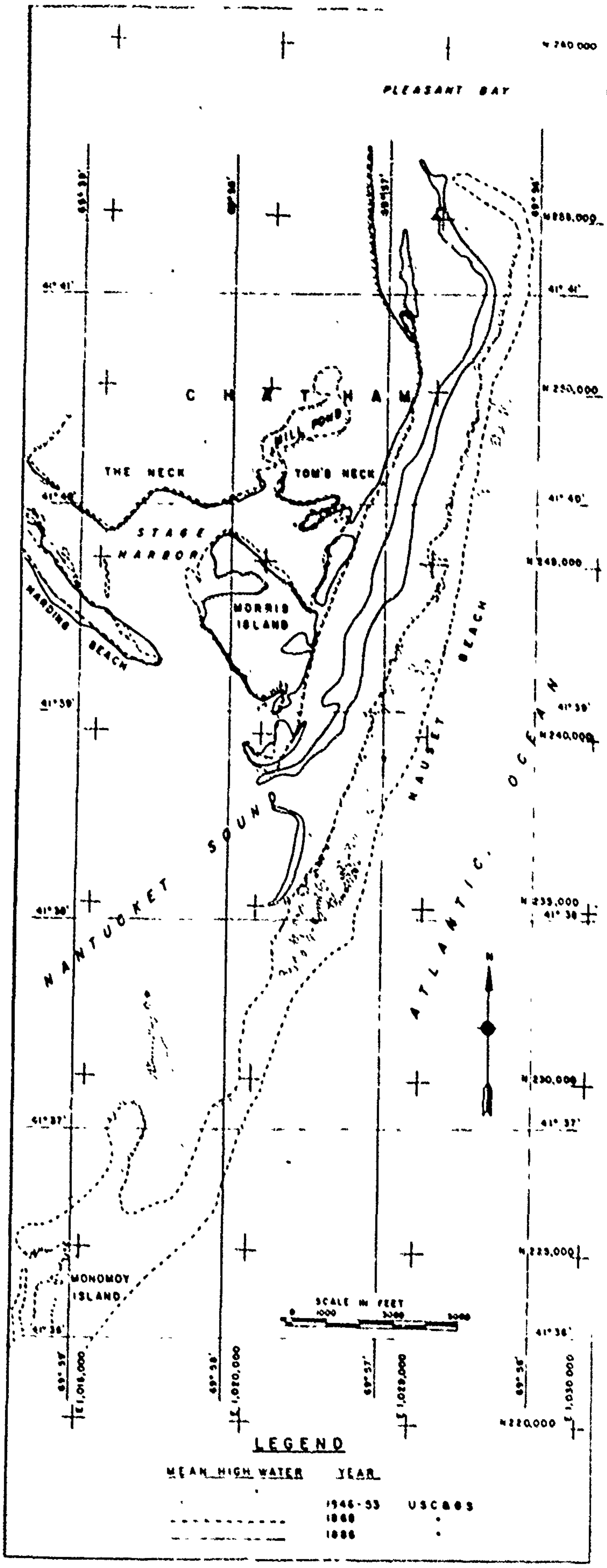


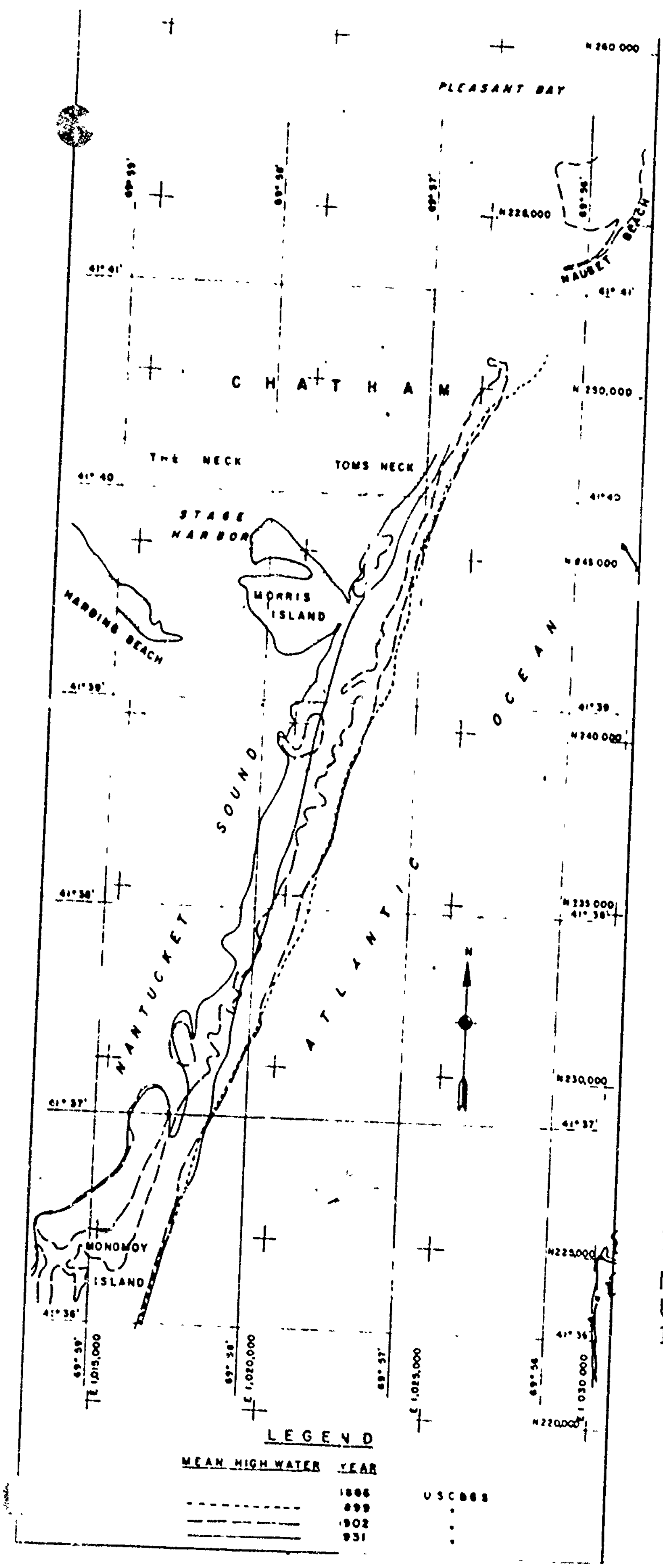
Figure 1-D23. Growth of the southern tip of Nauset Beach, Chatham, 1938-1971



A

Figure 1-D24.

Shoreline changes at the Southern tip of Nauset Beach and on Monomoy Islands, 1846-1965 (After U.S. Army Corps of Engineers, 1968) (Cont'd)



B

Figure 1-D24.

Shoreline changes at the Southern tip of Nauset Beach and on Monomoy Island, 1846-1965 (After U.S. Army Corps of Engineers, 1968) (Cont'd)

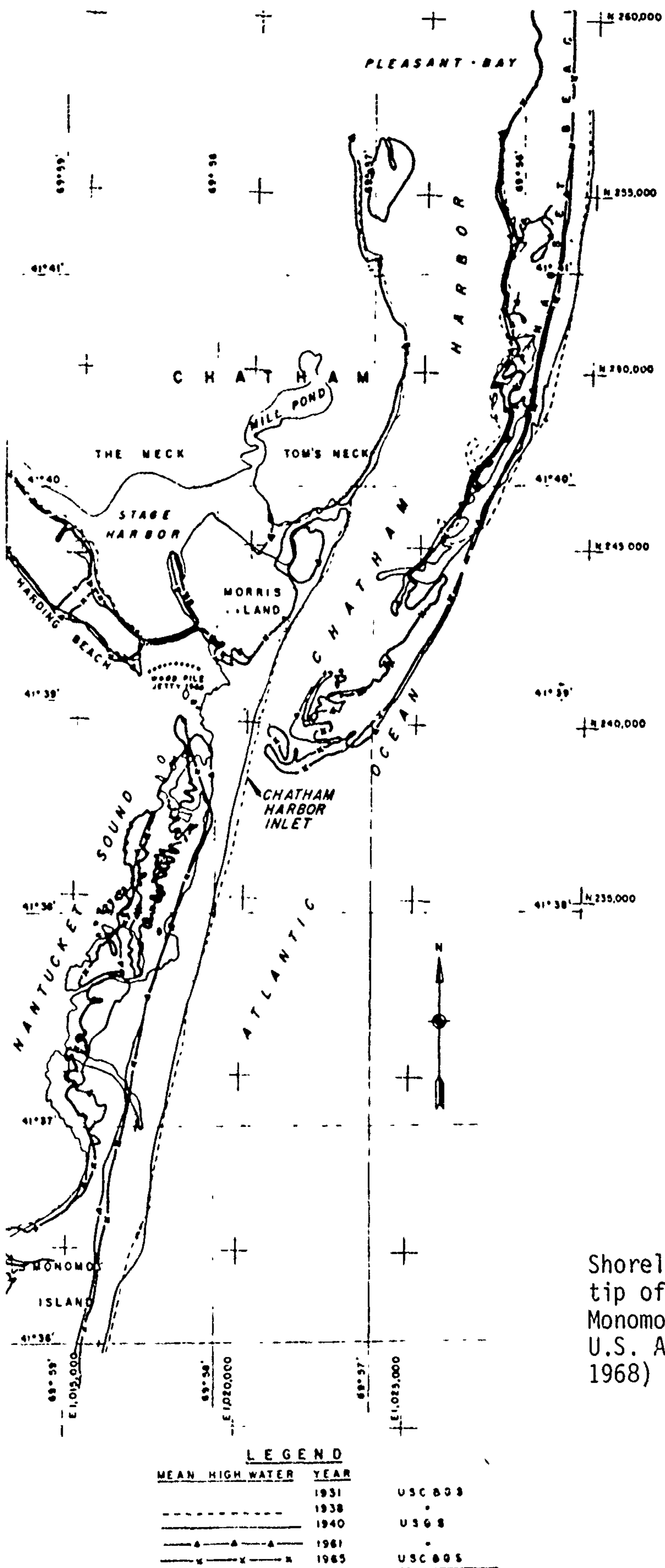


Figure 1-D24.

Shoreline changes at the Southern tip of Nauset Beach and on Monomoy Island, 1846-1965 (After U.S. Army Corps of Engineers, 1968) (Cont'd)

C

Waves and tidal currents widened the gap (U.S. Army Corps of Engineers, 1968) and the Great Atlantic Storm of March 1962 completed the separation (Gatto, 1975).

The breach between Morris and Monomoy Islands caused navigation problems that led the Corps of Engineers to recommend closing the existing opening between Nauset Beach and Monomoy. Extensive quantities of sand carried through the gap covered valuable shellfish beds just west of Monomoy Island in Nantucket Sound (U.S. Army Corps of Engineers, 1968).

Between 1940 and 1965, Monomoy's eastern shoreline was eroded in the northern portion of the island while accretion occurred to the south (Figure 1-D25). Between 1971 and 1974, however, this trend was partially reversed; the southern tip of Monomoy was eroded and migrated westward (Gatto, 1975).

Drastic changes in a short period of time are common on Monomoy, where net rates of change between 1938 and 1974 varied from 4.3 feet per year at one location to 50.0 feet per year at another location (Gatto, 1975). An example of the dramatic change is the rapid growth of the southern end of Monomoy Island, which was extended southward between 1856 and 1868 at a rate of 157 feet per year (Strahler, 1966). Storms can also cause extreme changes. Between 1 November 1969 and 19 January 1970 a severe storm caused the berm to retreat 50 feet (Goldsmith, 1972, and Hayes, 1972, cited in Gatto, 1975). Such changes indicate Monomoy's high variability in relatively short time periods.

Evidence of the variability can also be seen in a comparison of the 1938 and 1971 aerial photographs of Monomoy Point (Figure 1-D26). Areas on the southeast shore were produced by accretion and covered by vegetation between 1938 and 1971. In 1938, Powder Hole, a cove of Monomoy Point, was separated from Nantucket Sound by spits; a narrow inlet joined the cove and the sound. In the 1971 photo, Powder Hole is completely closed off by a wide barrier beach.

NODAL POINTS AND FULCRUM POINTS

Sand that is being transported north on the outer Cape Cod coast is building the northern shoreline of Provincetown seaward. Sand that is moving south has built spits at Nauset Harbor inlet, Nauset Beach and Monomoy Island. Because sand is being transported to the north on the northern part of the outer Cape shore, there must be a point where the net flow of sand changes from north to south. The location of this point, known as a nodal point, is not well established (Fisher, 1972).

Locations suggested as the possible site of the nodal point are listed in Table 1-D3. The nodal point location is uncertain because wave conditions are constantly changing. If waves always approached the Cape from one

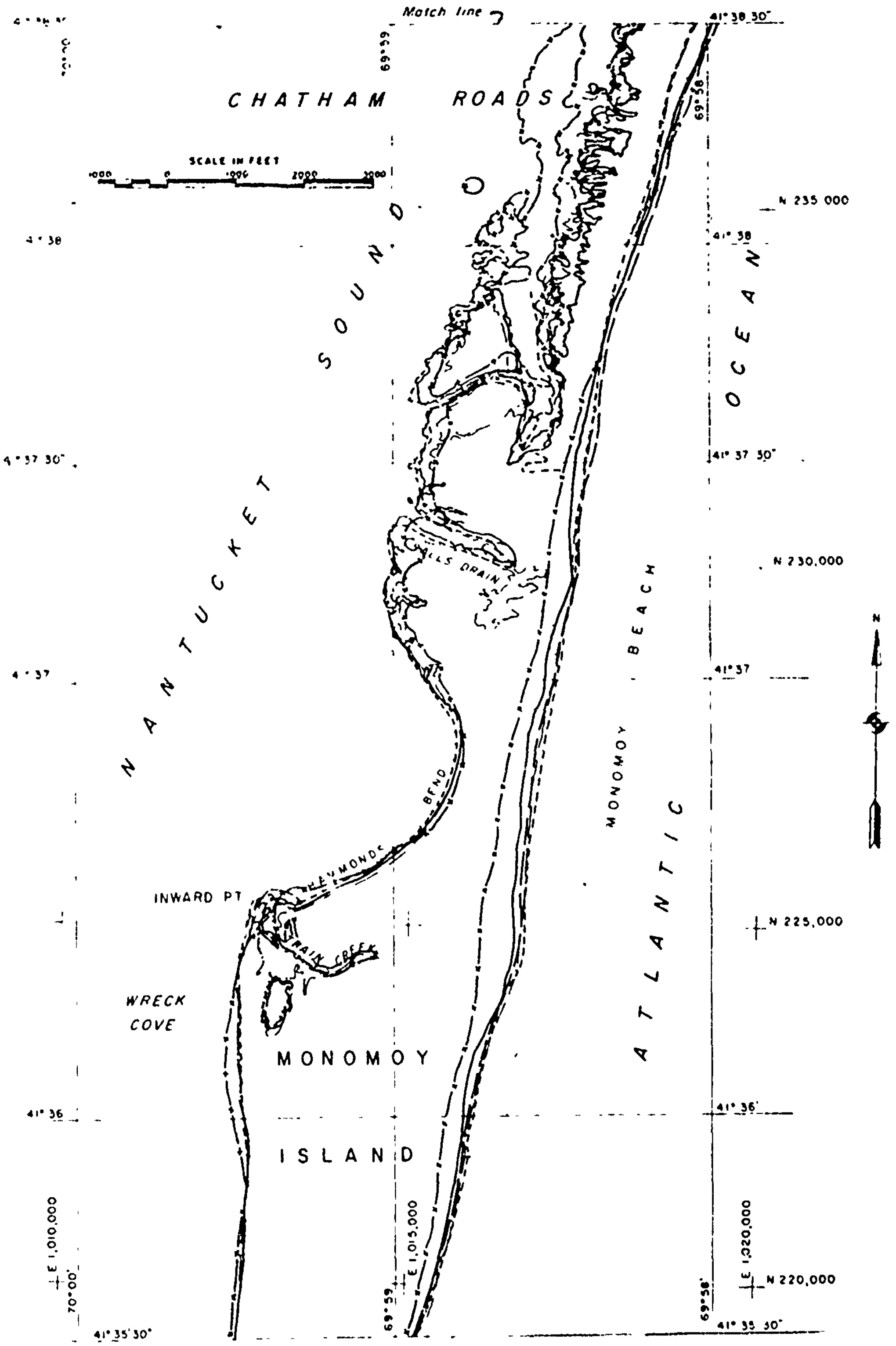


Figure 1-D25. Shoreline changes On Monomoy Island, 1940-1965
(After U.S. Army Corps of Engineers, 1968)

1938

Figure 1-D26. Southern tip of Monomoy Island, 1938 and 1971 (Cont'd)

1971

Figure 1-D26. Southern tip of Monomoy Island, 1938 and 1971

Table 1-D3. Suggested locations of the nodal point on the eastern shores of Cape Cod

STUDY	LOCATION
Schalk, 1938	Shoreline opposite the mouth of the Pamet River, Truro
Hartshorn et al, 1967	Near the center of the outer Cape
Fisher, 1972	Newcomb Hollow Beach, Wellfleet (just south of Gull Pond)
Gatto, 1975	Between Salt Meadow and the North Truro Air Force Station
Cornillon et al, 1976	LeCount Hollow Beach, Wellfleet

direction, the nodal point location could be determined. Nodal points for waves from a given direction as calculated in the wave refraction analysis are listed in Table 1-D4. Because the waves do not always approach the Cape from any one direction, the individual directions are combined to reflect the average wave conditions that occur during the year. Wave refraction analysis using the average wave conditions predicts that nodal points are located about 20, 35, 40 and 42 miles north of the tip of Nauset Beach, Chatham; the 20-mile mark is located near LeCount Hollow Beach.

SHORELINE CHANGES CAUSED BY STORMS

Introduction

Hurricanes or severe storms (particularly northeasters) that pass along the New England coast can greatly alter the beaches on Cape Cod's easterly shores. High winds blowing onshore can pile water against the coastline causing a storm surge. The reduction in barometric pressure associated with the storm also can cause the ocean surface to be higher than its normal level. As discussed in the hydrology section, this phenomenon can create a change in sea level of a little more than 1 foot when barometric pressure drops 1 inch. A storm surge can be especially damaging if it coincides with an astronomically high tide. Waves and surge combine to produce most of the damage due to storms.

When the surface level of the sea is elevated, storm-generated wind waves can reach parts of the beach that are not normally exposed to wave attack. Storm waves can be very steep and are capable of carrying large amounts of littoral material offshore (U.S. Army Coastal Engineering Research Center, 1975). Thus, single storms often cause more erosion than many months of less violent weather; however, the beach may return to fullness as rapidly as it is cut (Zeigler, 1956).

The amount of damage inflicted on a beach and the recovery time required to restore the beach may depend on the condition of the beach prior to the storm. If the beach berm is wide, even though it may be cut back during a storm, it may prevent damage to upland features. If the beach berm is not wide (for example, when one serious storm closely follows another), the backshore and cliffs or dunes may be seriously damaged. Zeigler (1956) hypothesized that the greatest erosion will occur when beaches are wasted, rather than during specific storms. Recovery time may be relatively short if the beach and berm were wide prior to the storm. If the beach was wasted before the storm's impact, replenishment time might be considerably longer (Zeigler, 1956).

Table 1-D4. Location of the nodal point on the eastern shores of Cape Cod for waves from one direction, wave Refraction analysis (After Cornillon et al, 1976)

DIRECTION FROM WHICH WAVE IS COMING	LOCATION OF NODAL POINT (miles north of the tip of Nauset Beach, Chatham)
NW	39
NNW	38
N	37
NNE	34
NE	29
ENE	24
E	9
ESE	2

It was found that several of the Cape's beaches were protected by offshore bars. Cuts in the beach seemed to appear opposite breaks in the bar. When bars were breached during storms, erosion was severe; slow beach recovery followed the reforming of the bar (Zeigler, 1960).

Numerous storms have affected Cape Cod. Several of the storms for which erosion has been documented are discussed below.

The Storm of 17 December 1970

Changes caused by the Atlantic coast storm of 17 December 1970 have been studied in detail by the Coastal Engineering Research Center of the Army Corps of Engineers (DeWall et al, 1977). Ten profile lines (Figure 1-D27) across the beach from the Truro-Wellfleet town line to Nauset Harbor inlet had been surveyed by the New England Division of the Army Corps of Engineers on 10 December 1970 and were resurveyed on 18 December 1970, the day after the storm.

The study (DeWall et al, 1977) showed a trend of decreasing erosion from north to south; this trend correlates with changes in beach morphology from the high (greater than 100 feet), actively eroding scarps at Wellfleet to the low, accreting spit at Nauset. Generally, erosion was found to be greatest on the upper part of the beach profiles [above +2 feet MSL (mean sea level)] with deposition occurring below +1 foot elevation.

Unit volume changes and movement of the shoreline caused by the storm are shown in Table 1-D5 and Figure 1-D28. The average volume lost above MSL between 10 and 18 December on the 10 Cape Cod profiles was 5.5 cubic yards per linear foot (or 8.1 cubic yards per linear foot if profile 06 is eliminated because of the suspiciously large accretion on the face of the cliff).

When erosion occurs, material is removed from the beach. This situation ordinarily causes the shoreline to retreat. When material is added to the beach (accretion), the shoreline usually advances. Therefore, volume change and shoreline-position change are generally considered to be equally good indicators of erosion or accretion. Six of the 10 Cape Cod profiles followed this general rule. That is, volume decreased when the shoreline retreated (profiles 02, 03, 04, and 09) or volume increased when the shoreline advanced (profiles 06 and 10). However, of the other four profiles, three exhibited an advance in the shoreline even though volume was lost (profiles 01, 07, and 08). In the remaining location (profile 05), volume was lost but the MSL contour did not move (DeWall et al, 1977).

Profile 01 is a good example of how the MSL contour can move seaward when volume has been lost. The MSL contour moved 86.7 feet seaward between 10 December 1970 and 18 December 1970. However, 65.0 cubic yards per linear foot were lost between MSL and +52 feet. The 18 December profile

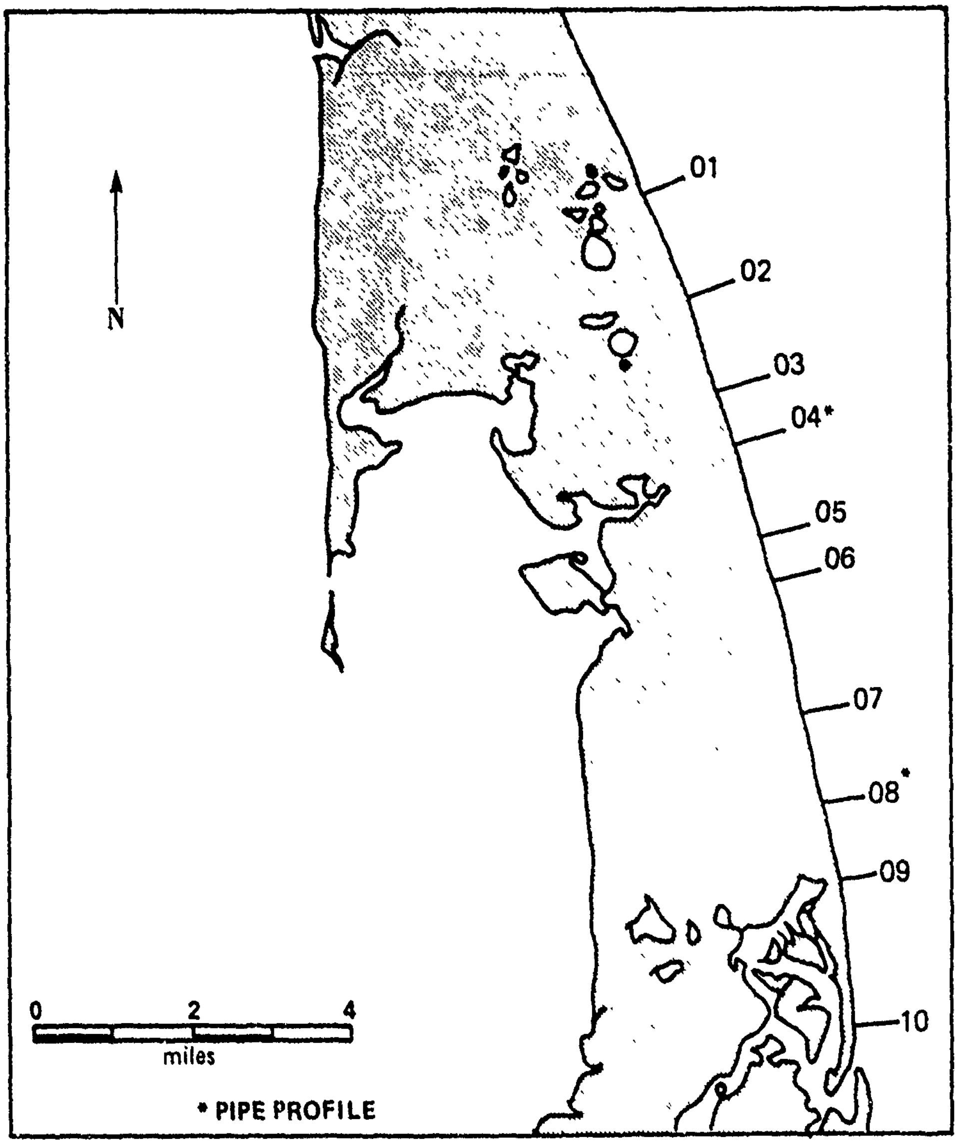


Figure 1-D27. Profile line locations (After DeWall et al, 1977)

Table 1-D5. Shoreline and unit volume changes at Cape Cod for 17 December 1970 storm

PROFILE LINE	MSL SHORELINE CHANGE (ft)	UNIT VOLUME CHANGE (cu. yd./ft.)
01	86.7	-21.7
02	-22.4	-12.9
03	- 7.9	-17.1
04	- 4.2	- 8.4
05	0.0	- 2.6
06	4.3	17.5
07	6.9	- 2.1
08	35.9	-10.2
09	- 2.7	- 6.3
10	66.7	8.8
Average	16.3	- 5.5[1]

Source: DeWall et al, 1977

[1]Average is -8.1 if data for Profile 06 is excluded.

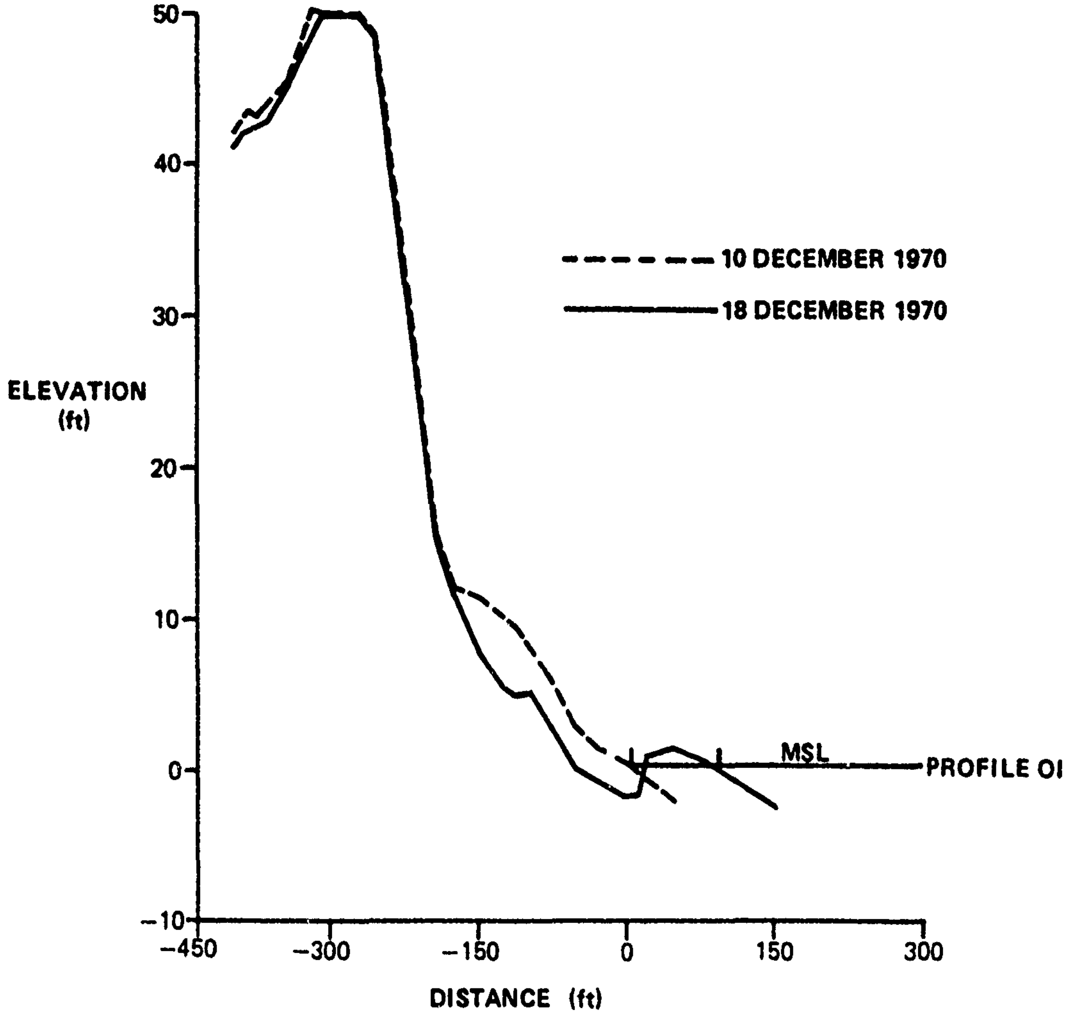


Figure 1-D28. Prestorm and poststorm surveys, profiles 01 through 10 (After DeWall et al, 1977)

indicates that erosion occurred on the upper profile and accretion produced a bar at the lower end of the profile (DeWall et al, 1977).

Study of this storm's passing also revealed that maximum erosion occurs at or above the maximum water elevation. Maximum deposition occurred below the maximum water elevation (Figure 1-D29). Erosion at high elevations on Cape Cod beaches probably resulted from the slumping of scarp material undermined by wave action at the scarp base (DeWall et al, 1977).

In summary, the 17 December 1970 storm produced an average net volume loss of 8.1 cubic yards per linear foot between MSL and the maximum elevation contour surveyed for each beach profile (Profile 06 is omitted from these data). Storms of this magnitude or greater generally occur twice a year.

Beach Changes Caused by Storms

Studies of Cape Cod beaches conducted by Woods Hole Oceanographic Institution (Zeigler, 1956) during a 33-month period also produced information about beach erosion during storms. During an October 1953 storm, the mean-high-water contour at Highland Light was driven landward 70 feet, and the beach was cut 4 feet, vertically. Shore erosion also resulted from a storm in October 1955 when the mean sea level contour was driven landward 85 feet and the beach was cut 10 feet vertically in one place. In both cases, the beach was rapidly replenished. Storms at Nauset Beach caused beach contours to be driven back as much as 75 feet, and vertical cuts of 5 to 6 feet were common.

During one particular year of the study (Zeigler, 1958), the final winter storm attacked a beach badly eroded by previous storms. This storm caused cliff cutting from Highland Light south to Nauset. Extensive cutting of the dunes on the north spit at Nauset occurred, and a new breakthrough was formed.

Thus, storms can be very efficient agents of erosion; the amount of material normally removed over a long period of time might be exceeded by one storm. Beaches are replenished following the storm, provided sufficient time elapses. However, if storms occur in rapid succession and the beach does not recover between storms, serious wasting of the beach and cutting of cliffs and dunes on the backshore may occur.

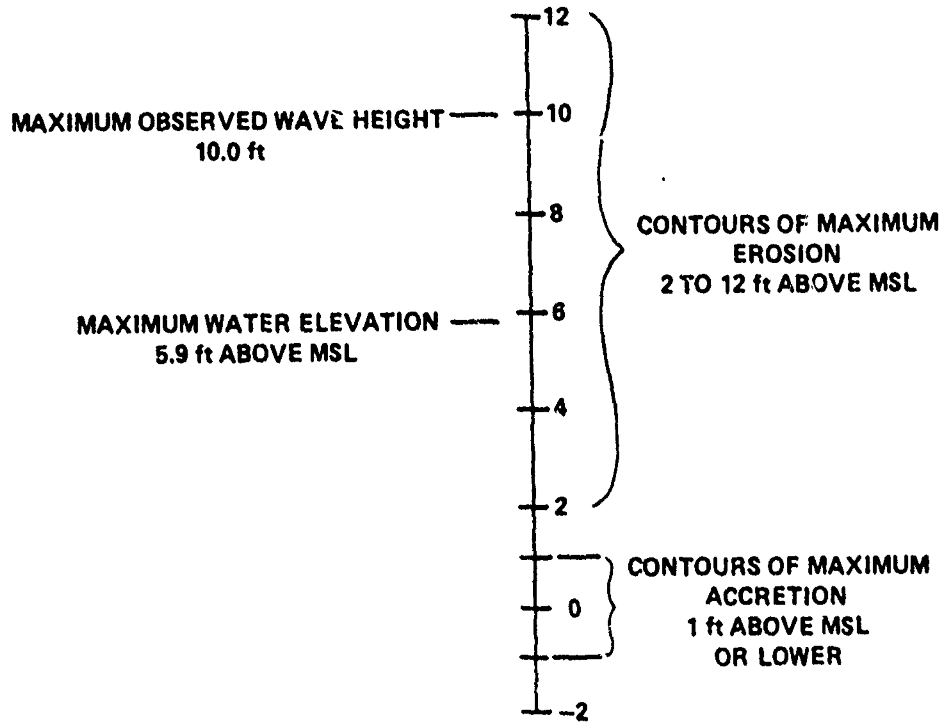
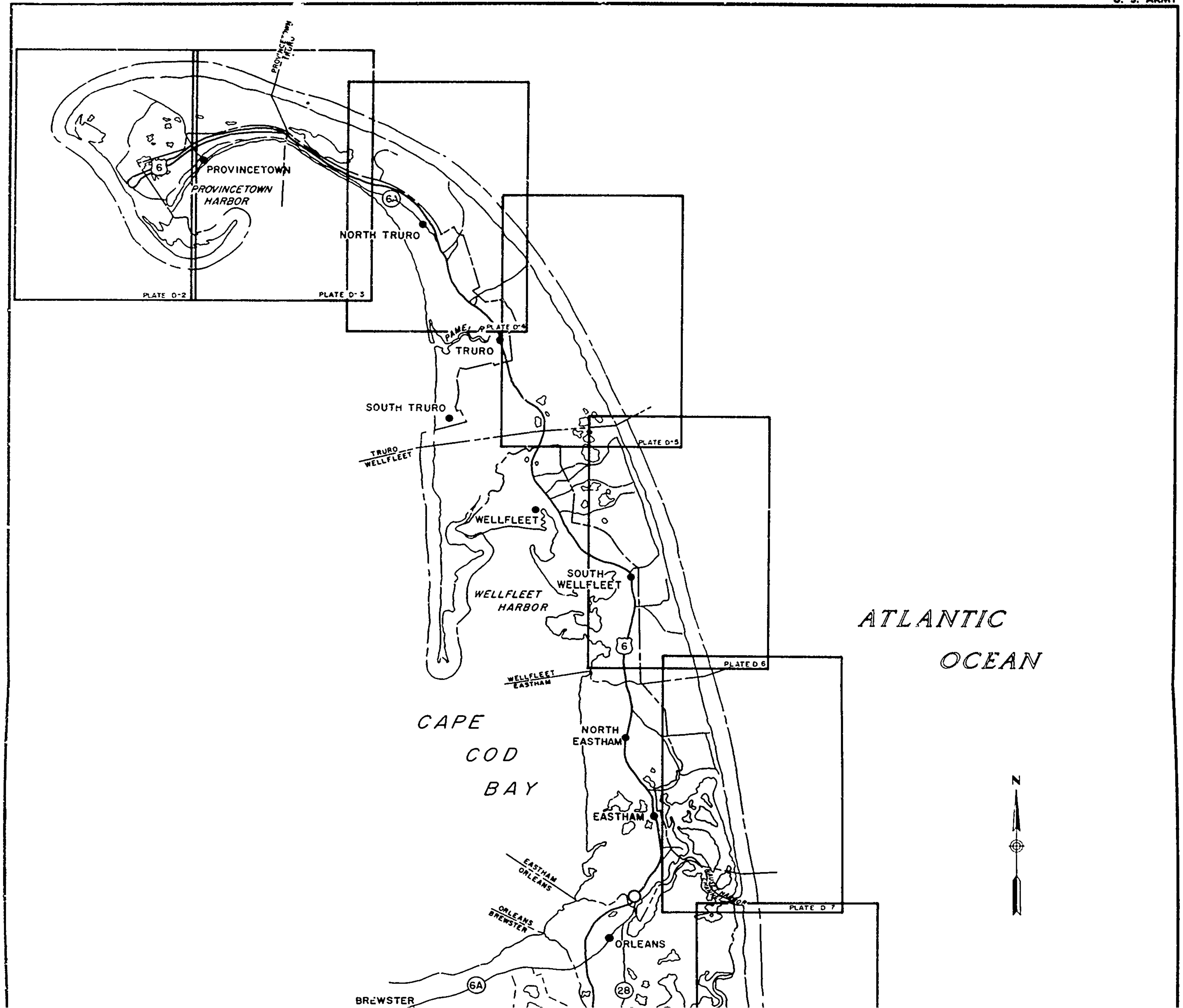


Figure 1-D29. Correlation between maximum water elevation and elevations of erosion and accretion (DeWall et al, 1977)


PROVINCETOWN
PROVINCETOWN HARBOR
PROVINCETOWN
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6
6A
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PLATE D-3
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PAMET R
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SOUTH TRURO
TRURO
WELLFLEET
PLATE D-5
WELLFLEET
SOUTH WELLFLEET
WELLFLEET HARBOR
ATLANTIC
OCEAN
WELLFLEET
EASTHAM
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COD
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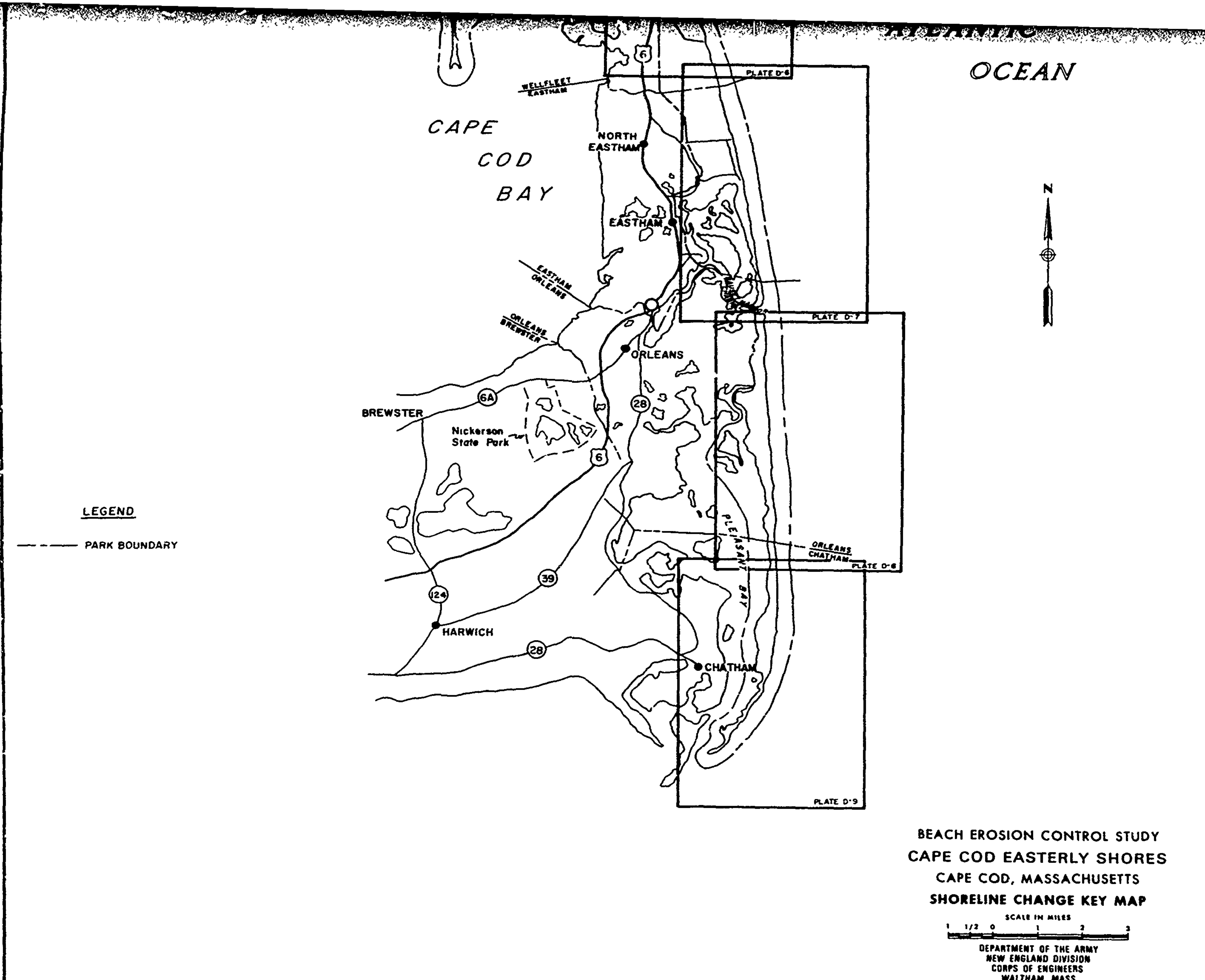
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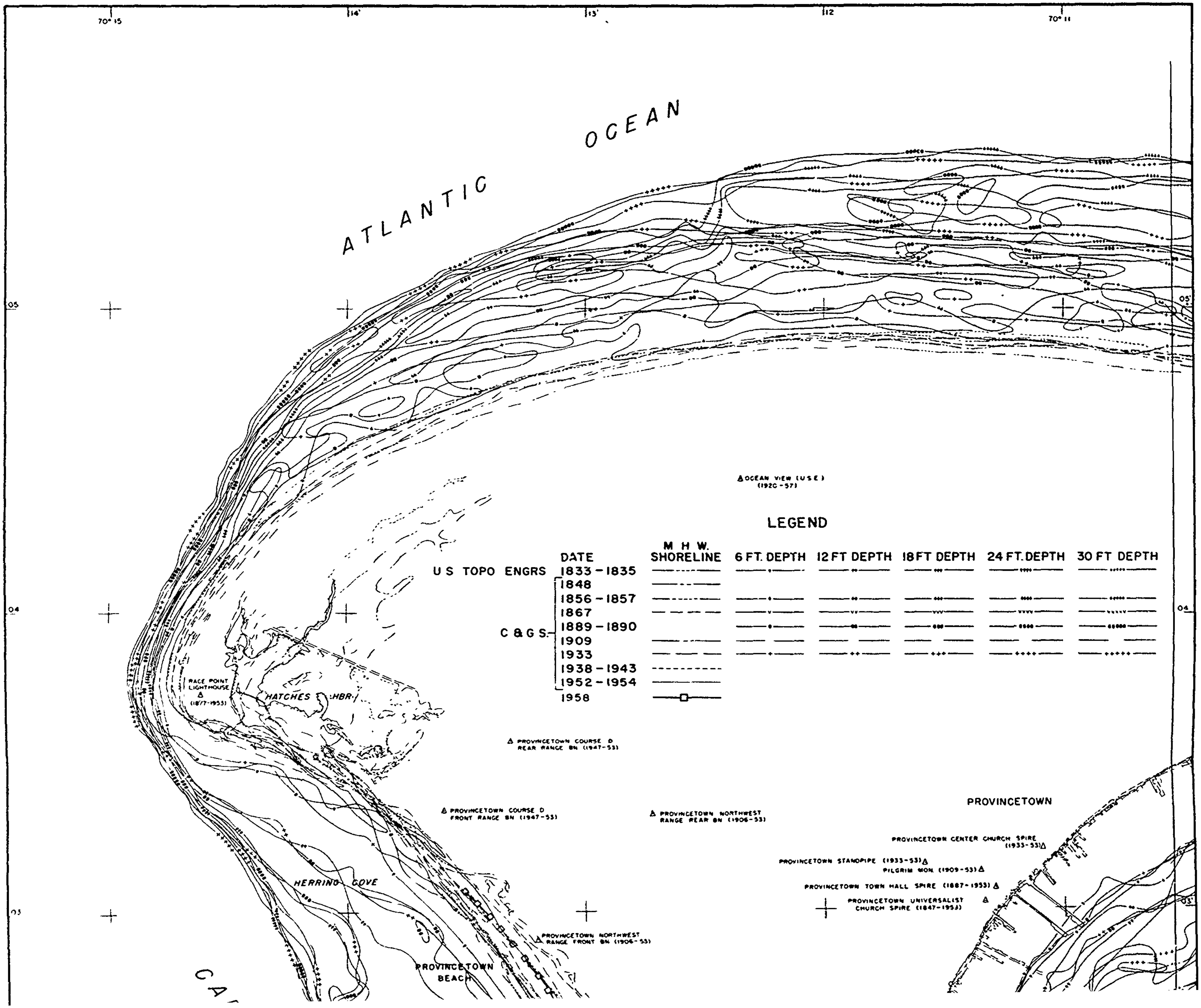
BREWSTER
Nickerson State Park
HARWICH
CHATHAM
PLEASANT BAY
ORLEANS
CHATHAM
PLATE D-6
PLATE D-7
PLATE D-8
PLATE D-9
6
6A
28
39
124
LEGEND
PARK BOUNDARY
BEACH EROSION CONTROL STUDY
CAPE COD EASTERLY SHORES
CAPE COD, MASSACHUSETTS
SHORELINE CHANGE KEY MAP
SCALE IN MILES
1 1/2 0 1 2 3
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS

PLATE D-1


70° 15
14'
13'
12
70° 11
05
04
03
ATLANTIC OCEAN
OCEAN VIEW (U S E) (1920-57)
LEGEND
DATE
M H W. SHORELINE
6 FT. DEPTH
12 FT DEPTH
18 FT DEPTH
24 FT. DEPTH
30 FT DEPTH
U S TOPO ENGRS 1833-1835
C & G S. 1848
1856-1857
1867
1889-1890
1909
1933
1938-1943
1952-1954
1958
RACE POINT LIGHTHOUSE (1877-1953)
HATCHES HBR
PROVINCETOWN COURSE D REAR RANGE BN (1947-53)
PROVINCETOWN COURSE D FRONT RANGE BN (1947-53)
PROVINCETOWN NORTHWEST RANGE REAR BN (1906-53)
PROVINCETOWN NORTHWEST RANGE FRONT BN (1906-53)
PROVINCETOWN
PROVINCETOWN CENTER CHURCH SPIRE (1933-53)
PROVINCETOWN STANDPIPE (1933-53)
PILGRIM MON. (1909-53)
PROVINCETOWN TOWN HALL SPIRE (1887-1953)
PROVINCETOWN UNIVERSALIST CHURCH SPIRE (1847-1953)
HERRING COVE
PROVINCETOWN BEACH

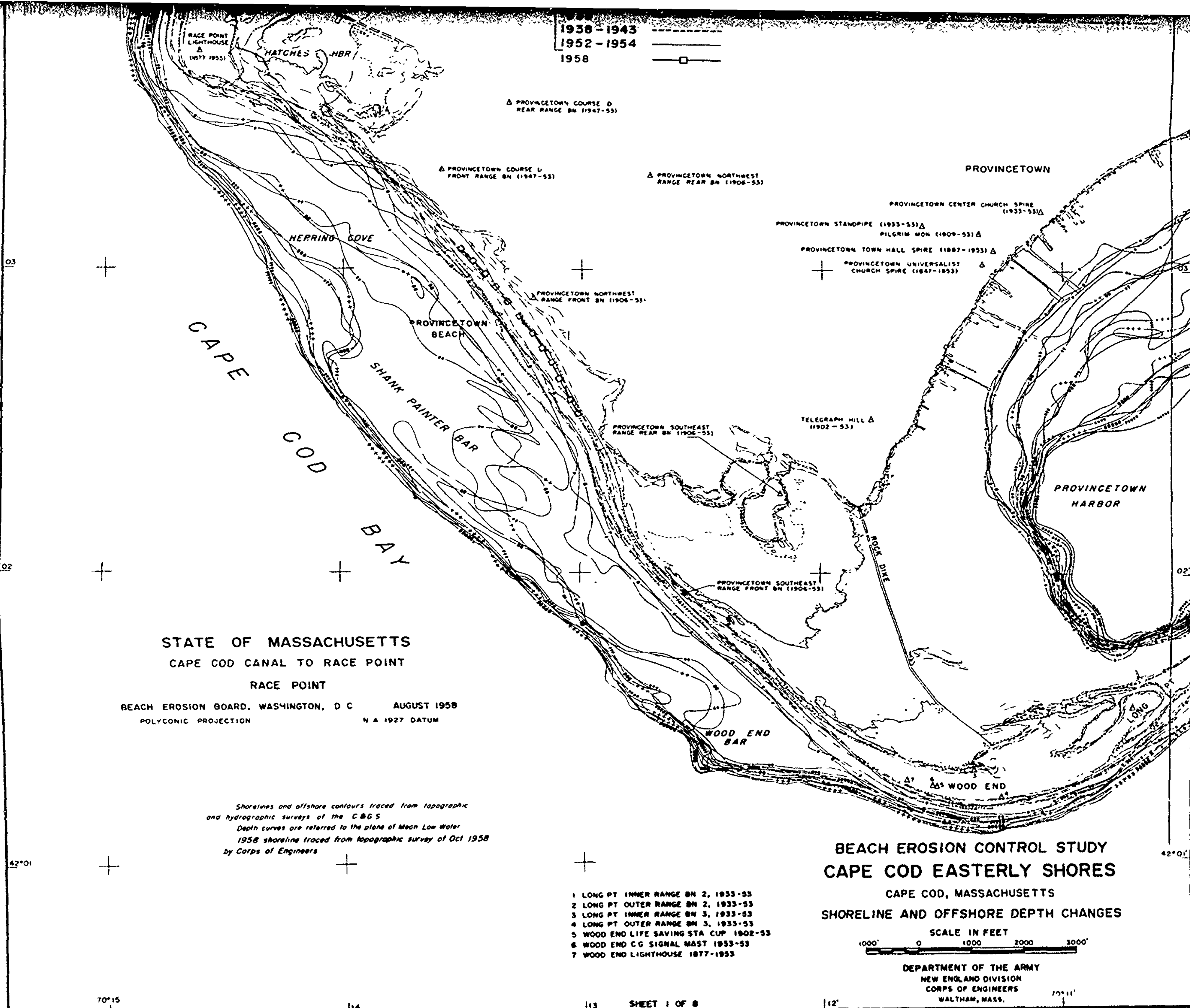
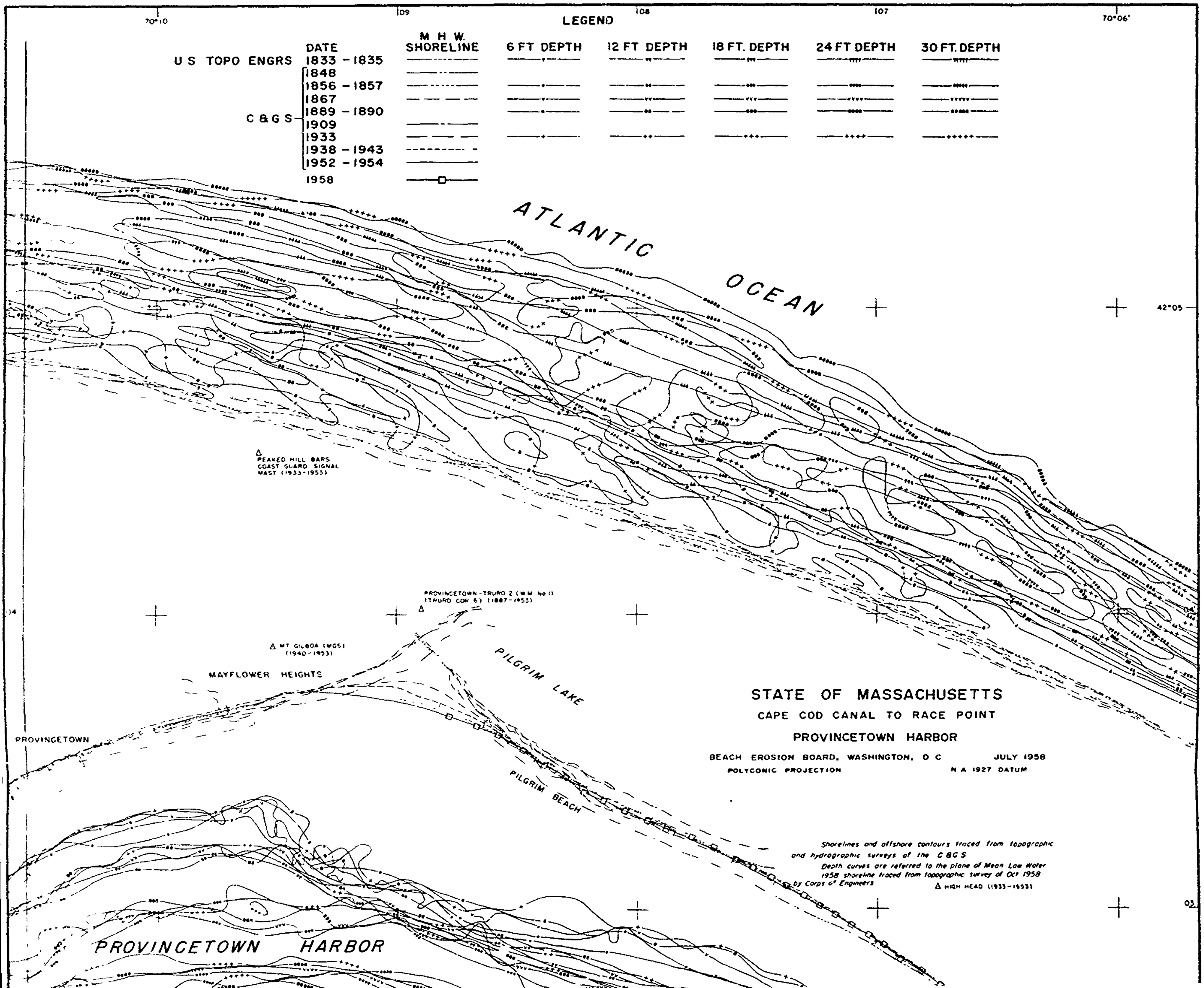

1938-1943
1952-1954
1958
RACE POINT LIGHTHOUSE (1877-1953)
HATCHES HBR
PROVINCETOWN COURSE D REAR RANGE BN (1947-53)
PROVINCETOWN COURSE D FRONT RANGE BN (1947-53)
PROVINCETOWN NORTHWEST RANGE REAR BN (1906-53)
PROVINCETOWN
PROVINCETOWN CENTER CHURCH SPIRE (1933-53)
PROVINCETOWN STANDPIPE (1933-53)
PILGRIM MON (1909-53)
PROVINCETOWN TOWN HALL SPIRE (1887-1953)
PROVINCETOWN UNIVERSALIST CHURCH SPIRE (1847-1953)
HERRING COVE
PROVINCETOWN NORTHWEST RANGE FRONT BN (1906-53)
PROVINCETOWN BEACH
SHANK PAINTER BAR
CAPE COD BAY
PROVINCETOWN SOUTHEAST RANGE REAR BN (1906-53)
TELEGRAPH HILL (1902-53)
PROVINCETOWN HARBOR
ROCK DIKE
PROVINCETOWN SOUTHEAST RANGE FRONT BN (1906-53)
STATE OF MASSACHUSETTS
CAPE COD CANAL TO RACE POINT
RACE POINT
BEACH EROSION BOARD, WASHINGTON, D C AUGUST 1958
POLYCONIC PROJECTION N A 1927 DATUM
WOOD END BAR
LONG PT
WOOD END
Shorelines and offshore contours traced from topographic and hydrographic surveys of the C&GS
Depth curves are referred to the plane of Mean Low Water
1958 shoreline traced from topographic survey of Oct 1958 by Corps of Engineers
BEACH EROSION CONTROL STUDY
CAPE COD EASTERLY SHORES
CAPE COD, MASSACHUSETTS
SHORELINE AND OFFSHORE DEPTH CHANGES
SCALE IN FEET
1000' 0 1000 2000 3000'
1 LONG PT INNER RANGE BN 2, 1933-53
2 LONG PT OUTER RANGE BN 2, 1933-53
3 LONG PT INNER RANGE BN 3, 1933-53
4 LONG PT OUTER RANGE BN 3, 1933-53
5 WOOD END LIFE SAVING STA CUP 1902-53
6 WOOD END CG SIGNAL MAST 1933-53
7 WOOD END LIGHTHOUSE 1877-1953
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.
SHEET 1 OF 8
70°15'
14
13
12'
70°11'
03
02
42°01'

PLATE D-2


LEGEND
DATE
M H W. SHORELINE
6 FT DEPTH
12 FT DEPTH
18 FT. DEPTH
24 FT DEPTH
30 FT. DEPTH
U S TOPO ENGRS 1833 - 1835
C & G S
1848
1856 - 1857
1867
1889 - 1890
1909
1933
1938 - 1943
1952 - 1954
1958
70°10
109
108
107
70°06'
42°05
04
03
ATLANTIC OCEAN
PEAKED HILL BARS COAST GUARD SIGNAL MAST (1933-1953)
PROVINCETOWN-TRURO 2 (W.M. No 1) (TRURO COR 6) (1887-1953)
MT GILBOA (MGS) (1940-1953)
MAYFLOWER HEIGHTS
PILGRIM LAKE
PILGRIM BEACH
PROVINCETOWN
PROVINCETOWN HARBOR
STATE OF MASSACHUSETTS
CAPE COD CANAL TO RACE POINT
PROVINCETOWN HARBOR
BEACH EROSION BOARD, WASHINGTON, D C
JULY 1958
POLYCONIC PROJECTION
N A 1927 DATUM
Shorelines and offshore contours traced from topographic and hydrographic surveys of the C&GS
Depth curves are referred to the plane of Mean Low Water
1958 shoreline traced from topographic survey of Oct 1958 by Corps of Engineers
HIGH HEAD (1933-1953)

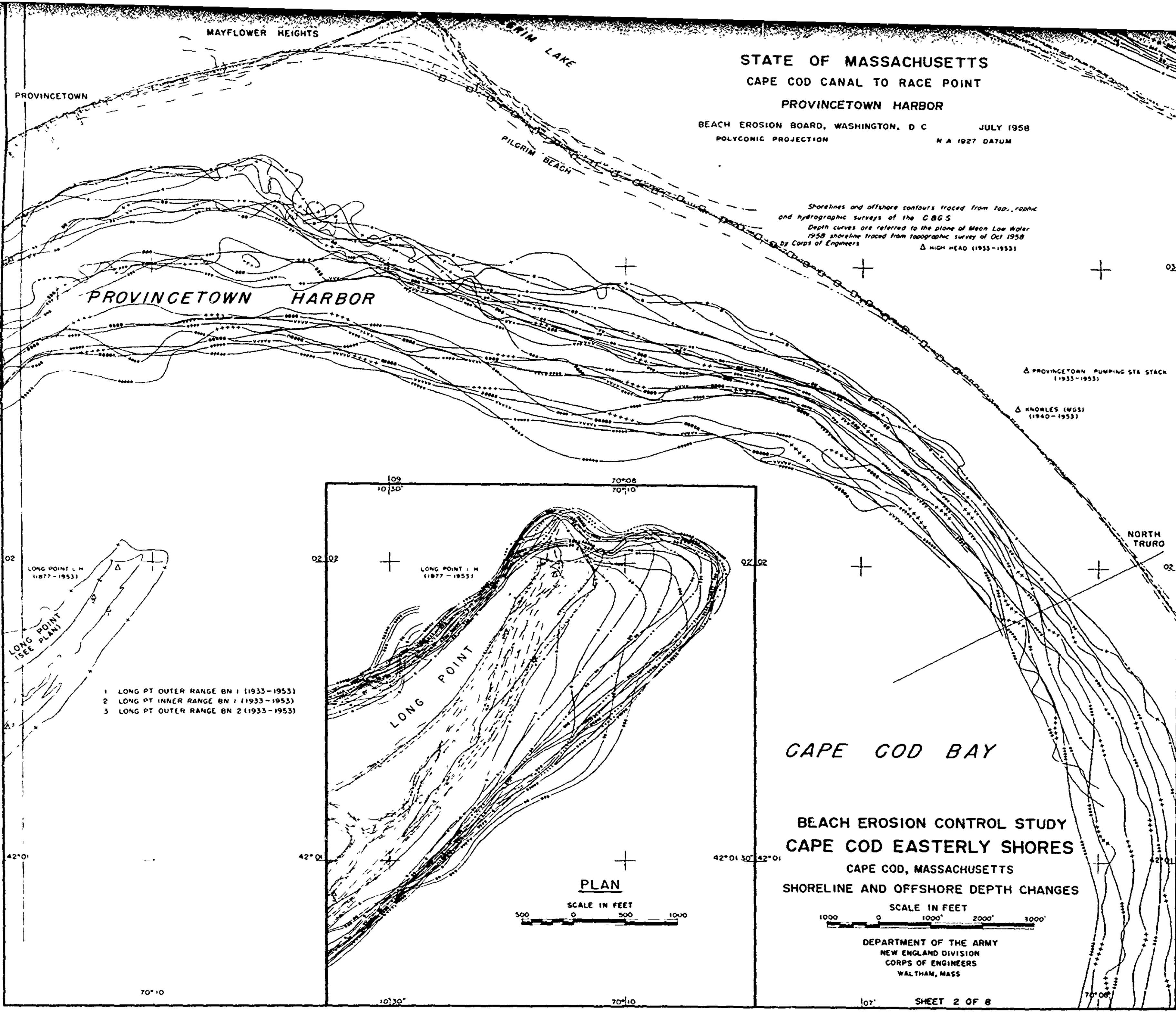
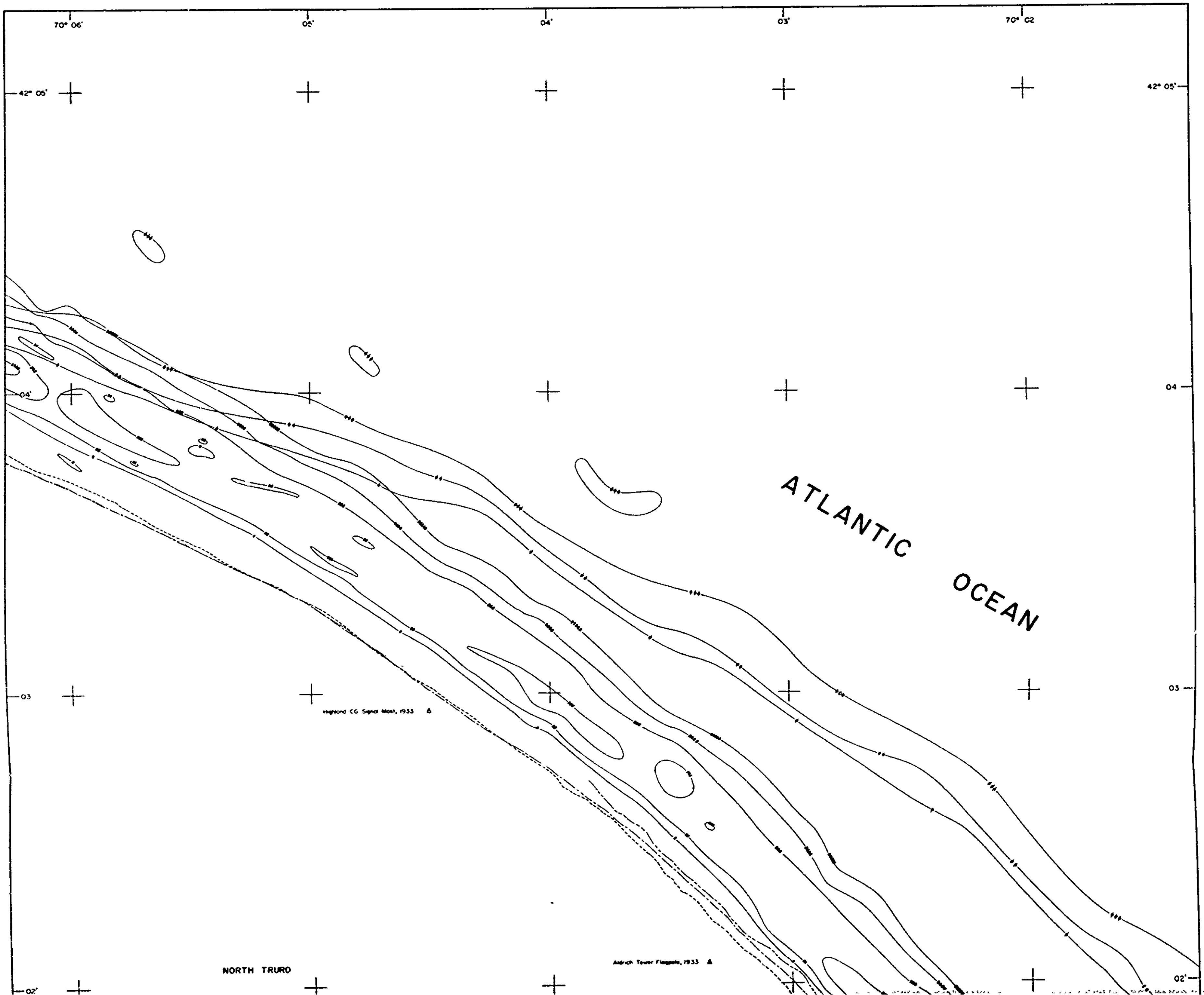
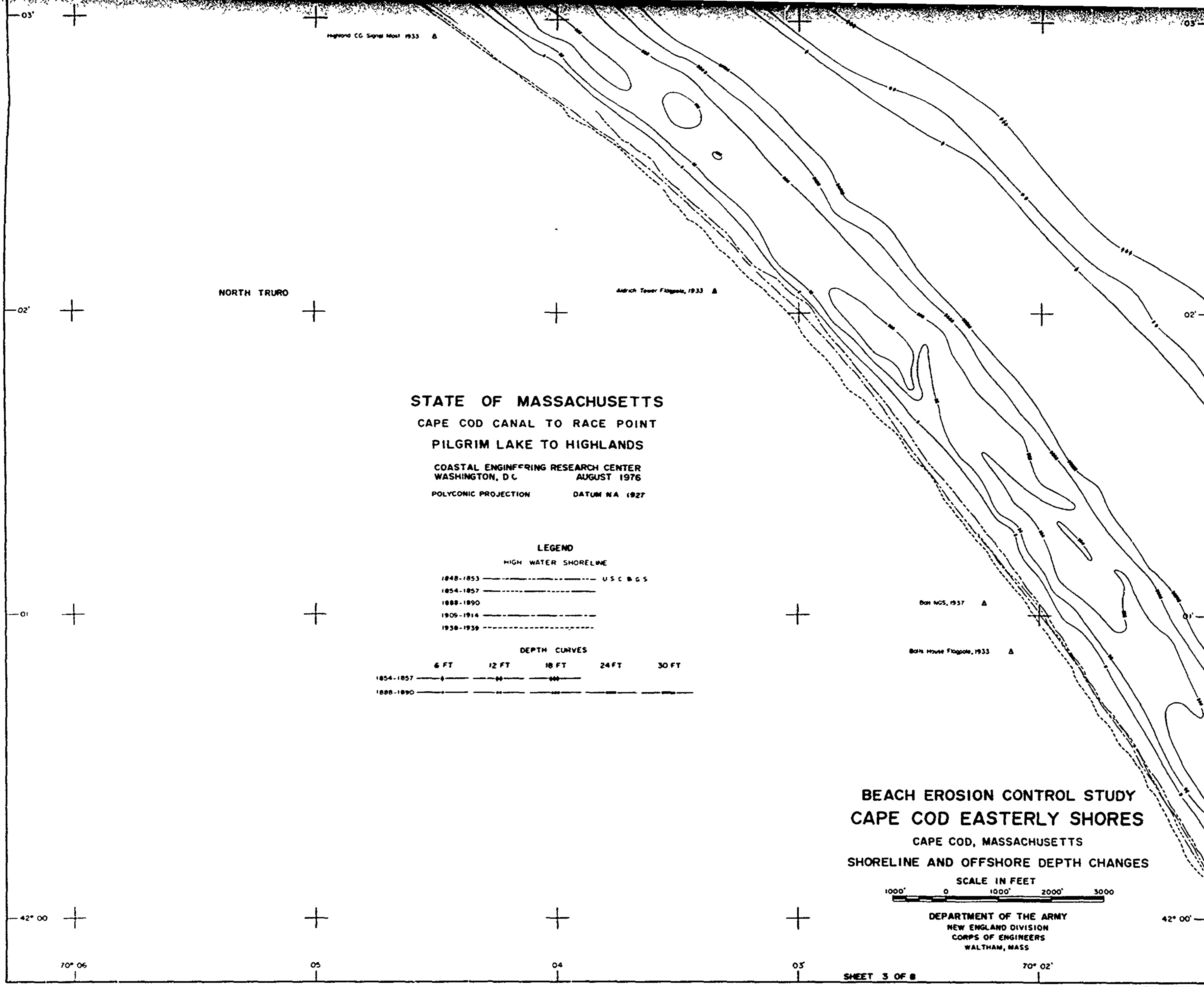

STATE OF MASSACHUSETTS
CAPE COD CANAL TO RACE POINT
PROVINCETOWN HARBOR
BEACH EROSION BOARD, WASHINGTON, D C
JULY 1958
POLYCONIC PROJECTION
N A 1927 DATUM
MAYFLOWER HEIGHTS
PROVINCETOWN
PILGRIM BEACH
PROVINCETOWN HARBOR
Shorelines and offshore contours traced from topographic and hydrographic surveys of the C&GS
Depth curves are referred to the plane of Mean Low Water
1958 shoreline traced from topographic survey of Oct 1958 by Corps of Engineers
Δ HIGH HEAD (1933-1953)
Δ PROVINCETOWN PUMPING STA STACK (1933-1953)
Δ KNOWLES (MGS) (1940-1953)
NORTH TRURO
LONG POINT L H (1877-1953)
LONG POINT (SEE PLAN)
1 LONG PT OUTER RANGE BN 1 (1933-1953)
2 LONG PT INNER RANGE BN 1 (1933-1953)
3 LONG PT OUTER RANGE BN 2 (1933-1953)
LONG POINT
PLAN
SCALE IN FEET
500 0 500 1000
CAPE COD BAY
BEACH EROSION CONTROL STUDY
CAPE COD EASTERLY SHORES
CAPE COD, MASSACHUSETTS
SHORELINE AND OFFSHORE DEPTH CHANGES
SCALE IN FEET
1000 0 1000' 2000' 3000'
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS
SHEET 2 OF 8

PLATE D-3

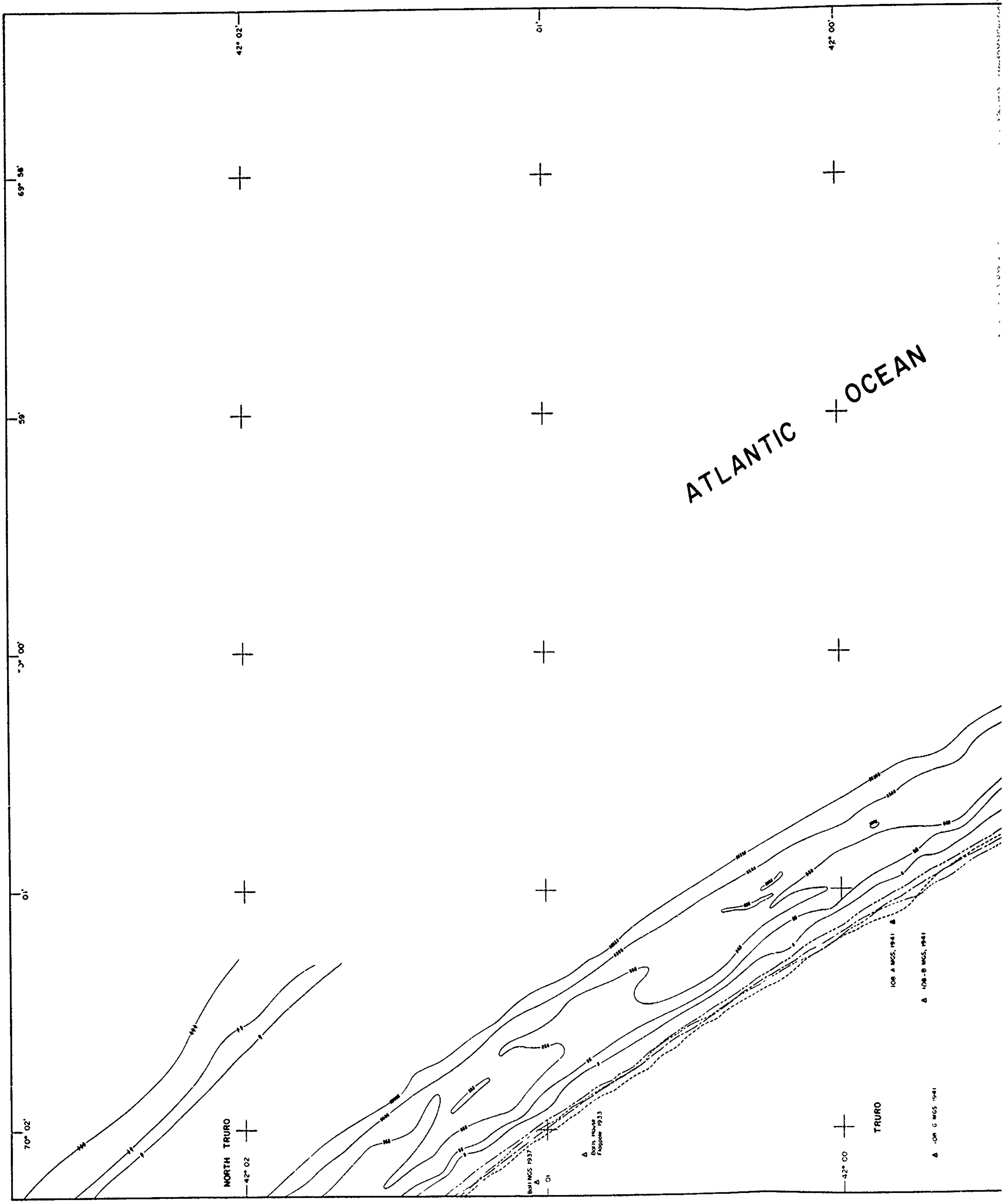


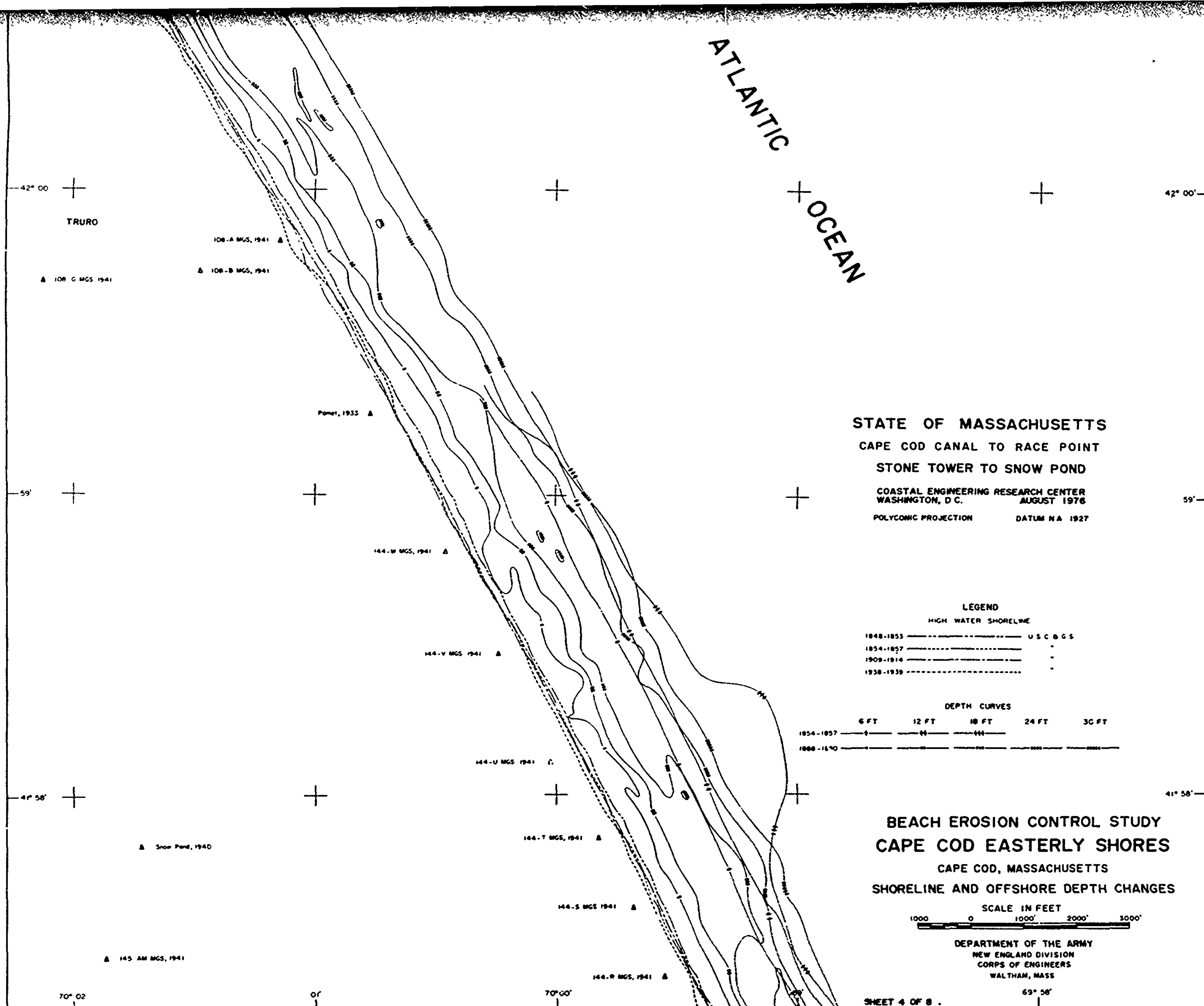
70° 06'
05'
04'
03'
70° 02
42° 05'
04
03
02'
ATLANTIC OCEAN
Highland CG Signal Mast, 1933
Aldrich Tower Flagpole, 1933
NORTH TRURO



Highland CG Signal Mast 1933
NORTH TRURO
Aldrich Tower Flagpole, 1933
Ball NGS, 1937
Balls House Flagpole, 1933
STATE OF MASSACHUSETTS
CAPE COD CANAL TO RACE POINT
PILGRIM LAKE TO HIGHLANDS
COASTAL ENGINEERING RESEARCH CENTER
WASHINGTON, D C
AUGUST 1976
POLYCONIC PROJECTION
DATUM NA 1927
LEGEND
HIGH WATER SHORELINE
1848-1853
U S C & G S
1854-1857
1888-1890
1905-1914
1938-1939
DEPTH CURVES
6 FT
12 FT
18 FT
24 FT
30 FT
1854-1857
1888-1890
BEACH EROSION CONTROL STUDY
CAPE COD EASTERLY SHORES
CAPE COD, MASSACHUSETTS
SHORELINE AND OFFSHORE DEPTH CHANGES
SCALE IN FEET
1000' 0 1000' 2000' 3000
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS
70° 06
05
04
03'
70° 02'
03'
02'
01
42° 00
SHEET 3 OF 8

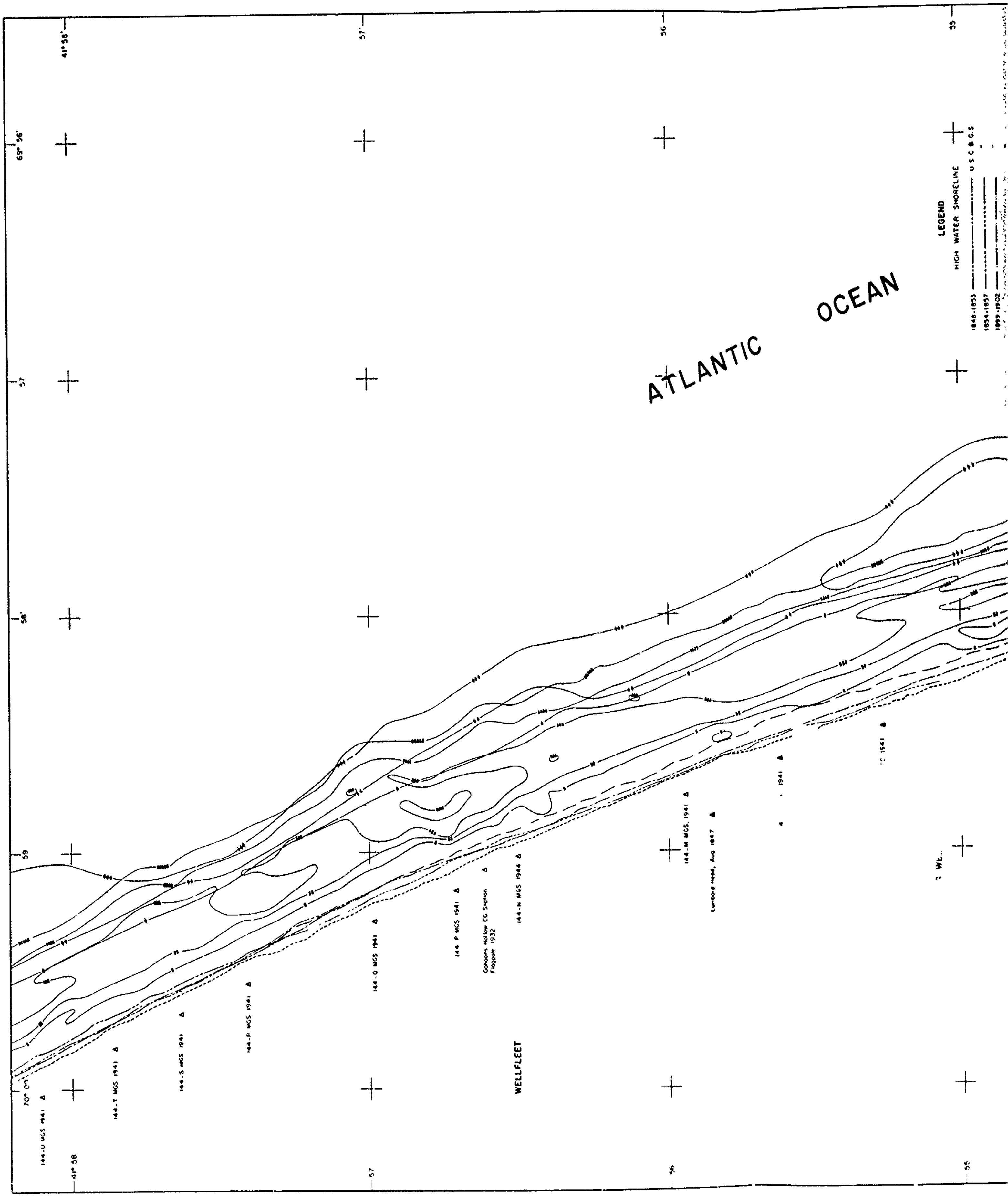
PLATE D-4


ATLANTIC OCEAN
NORTH TRURO
TRURO
42° 02'
01'
42° 00'
69° 58'
59'
70° 02'

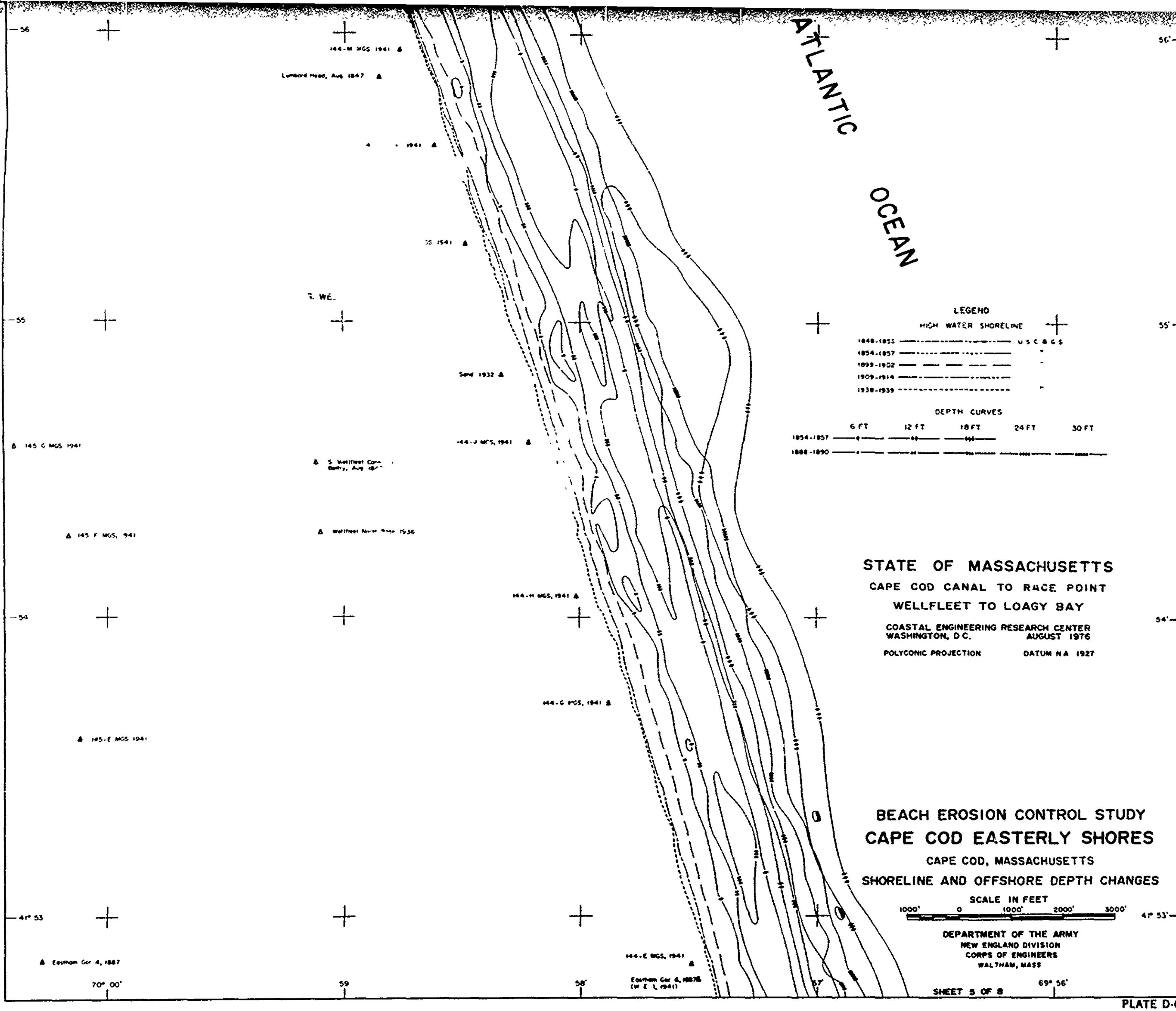


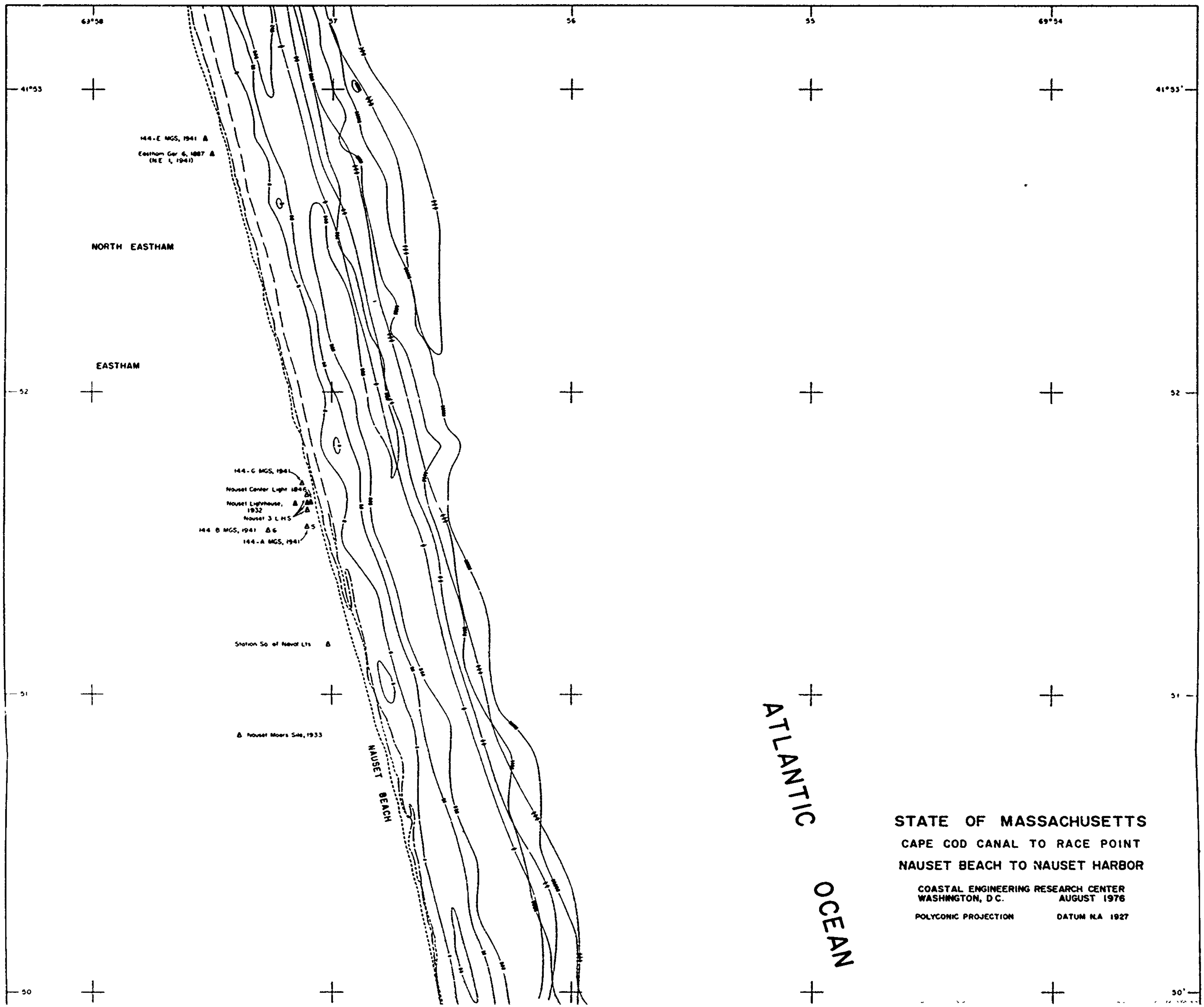
ATLANTIC OCEAN
42° 00'
59'
41° 58'
70° 02
01'
70°00'
69° 58'
TRURO
108 G MGS 1941
108-A MGS, 1941
108-B MGS, 1941
Pamet, 1933
144-W MGS, 1941
144-V MGS 1941
144-U MGS 1941
144-T MGS, 1941
144-S MGS 1941
144-R MGS, 1941
Snow Pond, 1940
145 AM MGS, 1941
STATE OF MASSACHUSETTS
CAPE COD CANAL TO RACE POINT
STONE TOWER TO SNOW POND
COASTAL ENGINEERING RESEARCH CENTER
WASHINGTON, D.C. AUGUST 1976
POLYCONIC PROJECTION DATUM N.A. 1927
LEGEND
HIGH WATER SHORELINE
1848-1853 U.S.C.&G.S.
1854-1857
1909-1914
1938-1939
DEPTH CURVES
6 FT 12 FT 18 FT 24 FT 30 FT
1854-1857
1888-1890
BEACH EROSION CONTROL STUDY
CAPE COD EASTERLY SHORES
CAPE COD, MASSACHUSETTS
SHORELINE AND OFFSHORE DEPTH CHANGES
SCALE IN FEET
1000 0 1000' 2000' 3000'
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS
SHEET 4 OF 8.

PLATE D-5



ATLANTIC OCEAN
LEGEND
HIGH WATER SHORELINE
1848-1853
1854-1857
1899-1902
U S C & G S
WELLFLEET
144-U MGS 1941
144-T MGS 1941
144-S MGS 1941
144-R MGS 1941
144-Q MGS 1941
144 P MGS 1941
Cahoons Hollow CG Station Flagpole 1932
144-N MGS 1944
144-M MGS 1941
Lumbert Head, Aug 1847
41° 58'
57'
56
55
69° 56'
57
58
59
70° 00'


ATLANTIC OCEAN
LEGEND
HIGH WATER SHORELINE
1848-1855 U.S.C.&G.S.
1854-1857
1899-1902
1909-1914
1938-1939
DEPTH CURVES
6 FT 12 FT 18 FT 24 FT 30 FT
1854-1857
1888-1890
STATE OF MASSACHUSETTS
CAPE COD CANAL TO RACE POINT
WELLFLEET TO LOAGY BAY
COASTAL ENGINEERING RESEARCH CENTER
WASHINGTON, D.C.
AUGUST 1976
POLYCONIC PROJECTION
DATUM N.A. 1927
BEACH EROSION CONTROL STUDY
CAPE COD EASTERLY SHORES
CAPE COD, MASSACHUSETTS
SHORELINE AND OFFSHORE DEPTH CHANGES
SCALE IN FEET
1000' 0 1000' 2000' 3000'
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS
SHEET 5 OF 8
PLATE D-6
Lombard Head, Aug 1847
Sand 1932
Wellfleet North Base 1936
70° 00'
59
58'
57'
69° 56'
41° 53'
54'
55'
56'



STATE OF MASSACHUSETTS
CAPE COD CANAL TO RACE POINT
NAUSET BEACH TO NAUSET HARBOR
COASTAL ENGINEERING RESEARCH CENTER
WASHINGTON, D.C.
AUGUST 1976
POLYCONIC PROJECTION
DATUM N.A. 1927
ATLANTIC OCEAN
NAUSET BEACH
NORTH EASTHAM
EASTHAM
144-E MGS, 1941
Eastham Ger. 6, 1887
(N.E. 1, 1941)
144-G MGS, 1941
Nauset Center Light 1846
Nauset Lighthouse, 1932
Nauset 3 L.H.S.
144 B MGS, 1941
144-A MGS, 1941
Station So. of Naval Lts.
Nauset Moors Site, 1933
69°58
57
56
55
69°54
41°53
52
51
50
41°53'
50'

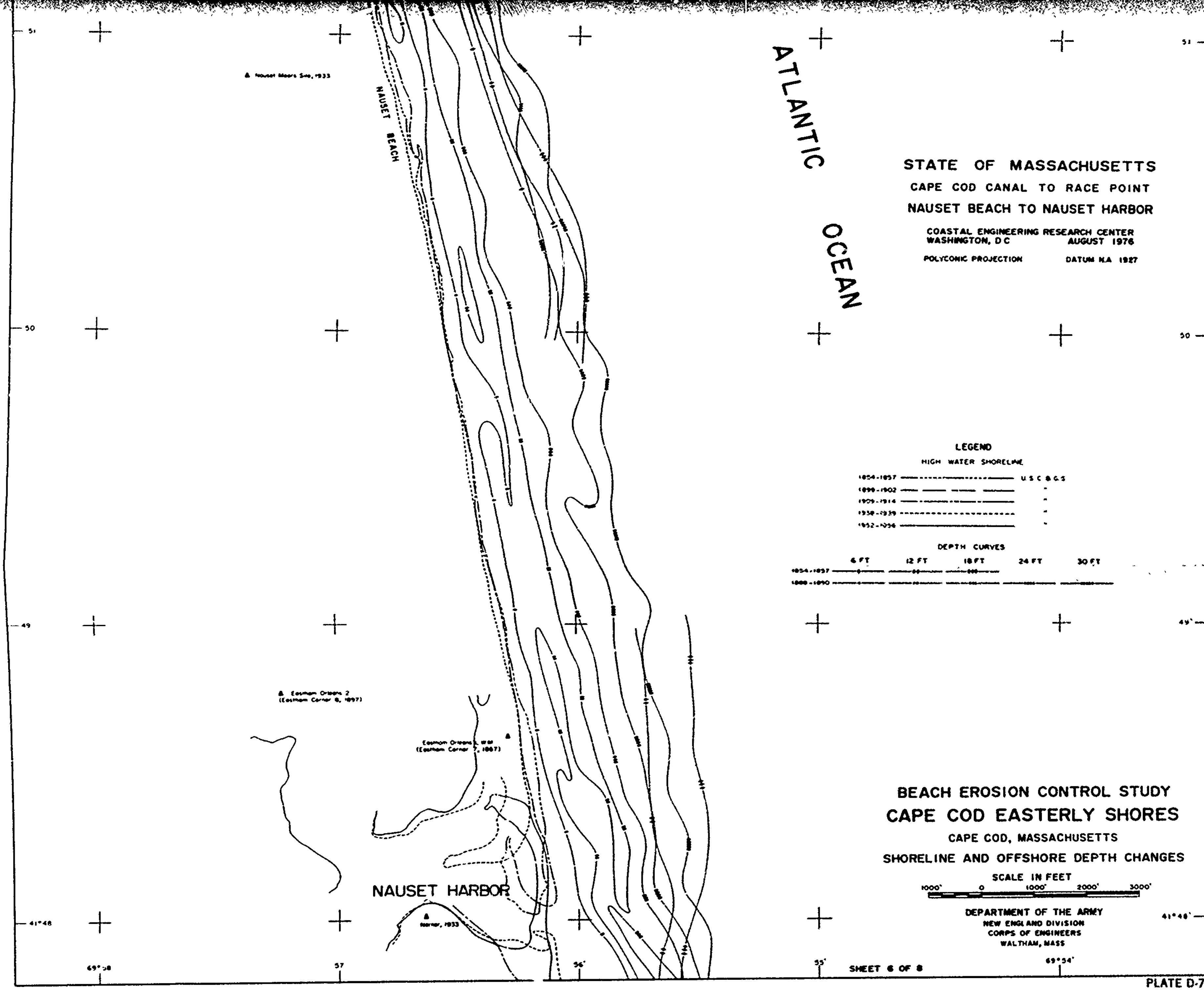
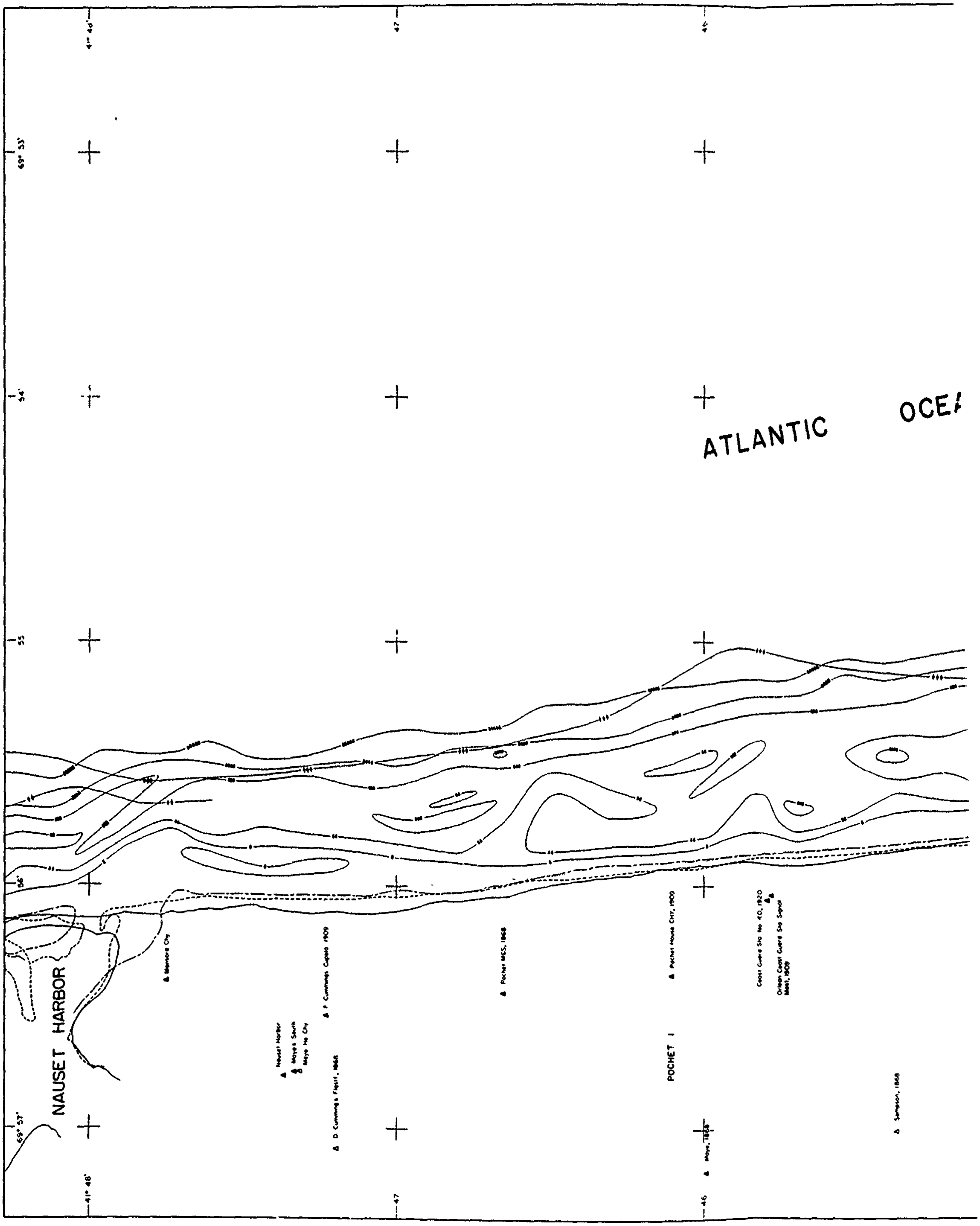

ATLANTIC OCEAN
STATE OF MASSACHUSETTS
CAPE COD CANAL TO RACE POINT
NAUSET BEACH TO NAUSET HARBOR
COASTAL ENGINEERING RESEARCH CENTER
WASHINGTON, D C
AUGUST 1976
POLYCONIC PROJECTION
DATUM N.A 1927
LEGEND
HIGH WATER SHORELINE
1854-1857
U.S.C.&G.S.
1899-1902
1909-1914
1938-1939
1952-1956
DEPTH CURVES
6 FT
12 FT
18 FT
24 FT
30 FT
1854-1857
1888-1890
NAUSET BEACH
NAUSET HARBOR
BEACH EROSION CONTROL STUDY
CAPE COD EASTERLY SHORES
CAPE COD, MASSACHUSETTS
SHORELINE AND OFFSHORE DEPTH CHANGES
SCALE IN FEET
1000'
0
1000'
2000'
3000'
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS
SHEET 6 OF 8
PLATE D-7

Table 1-C2. Suggested locations of the nodal point on the eastern shore of Cape Cod

STUDY	LOCATION
Schalk, 1938	Shoreline opposite the mouth of the Pamet River, Truro
Hartshorn et al, 1967	Near the center of the outer Cape
Fisher, 1972	Newcomb Hollow Beach, Wellfleet (just south of Gull Pond)
Gatto, 1975	Between Salt Meadow and the North Truro Air Force Station
Cornillon et al, 1976	LeCount Hollow Beach, Wellfleet


ATLANTIC
NAUSET HARBOR
POCHET I

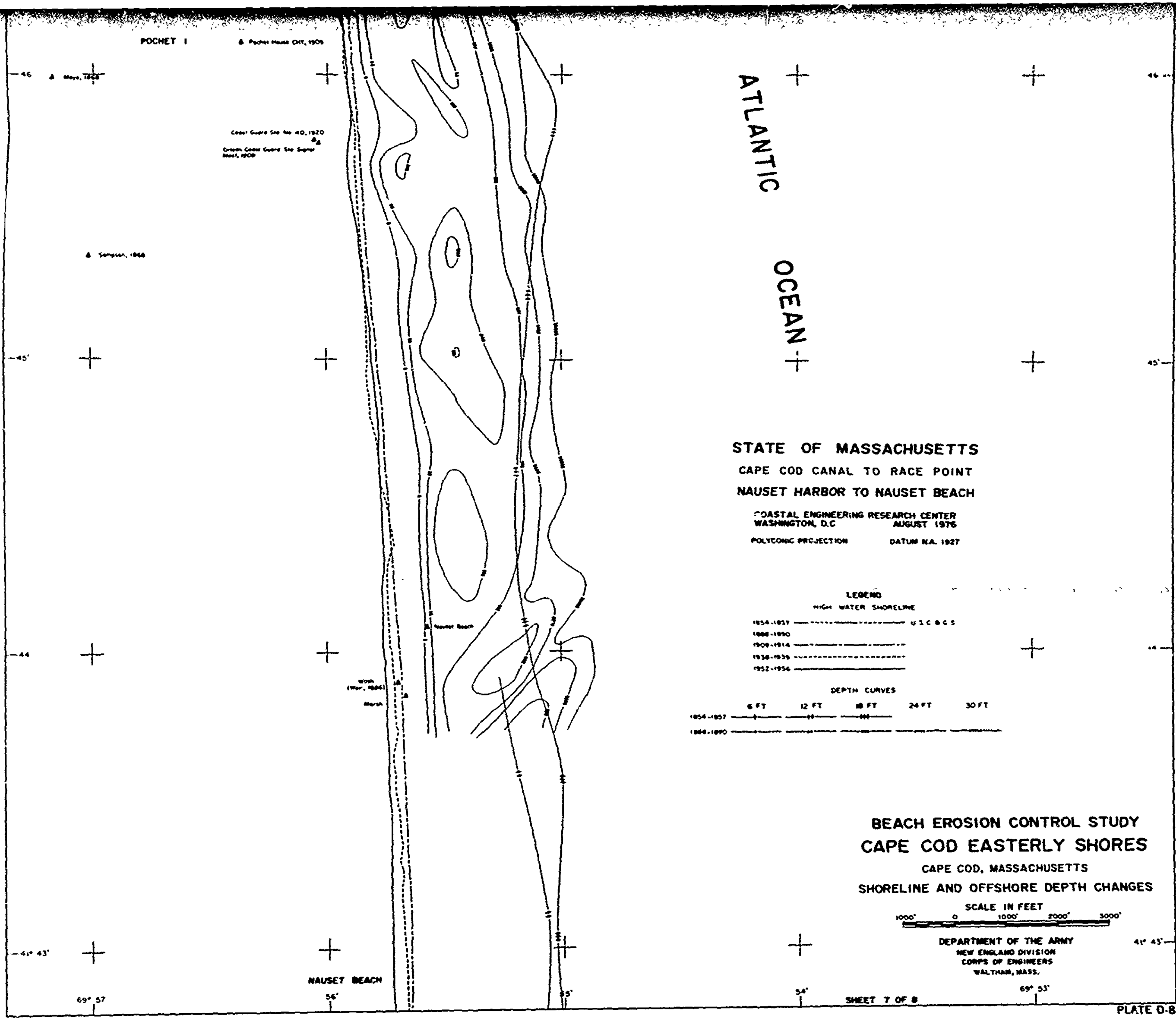
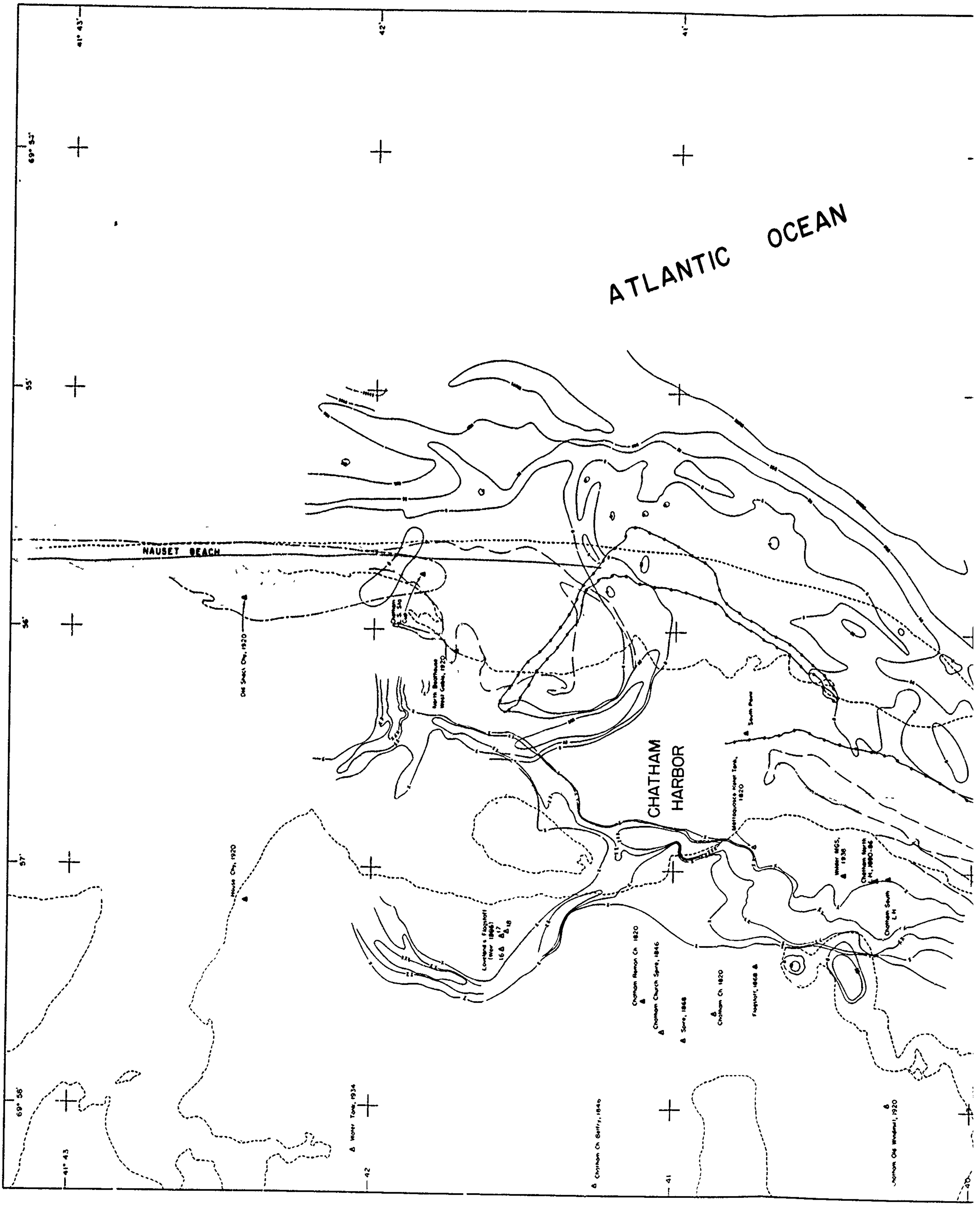
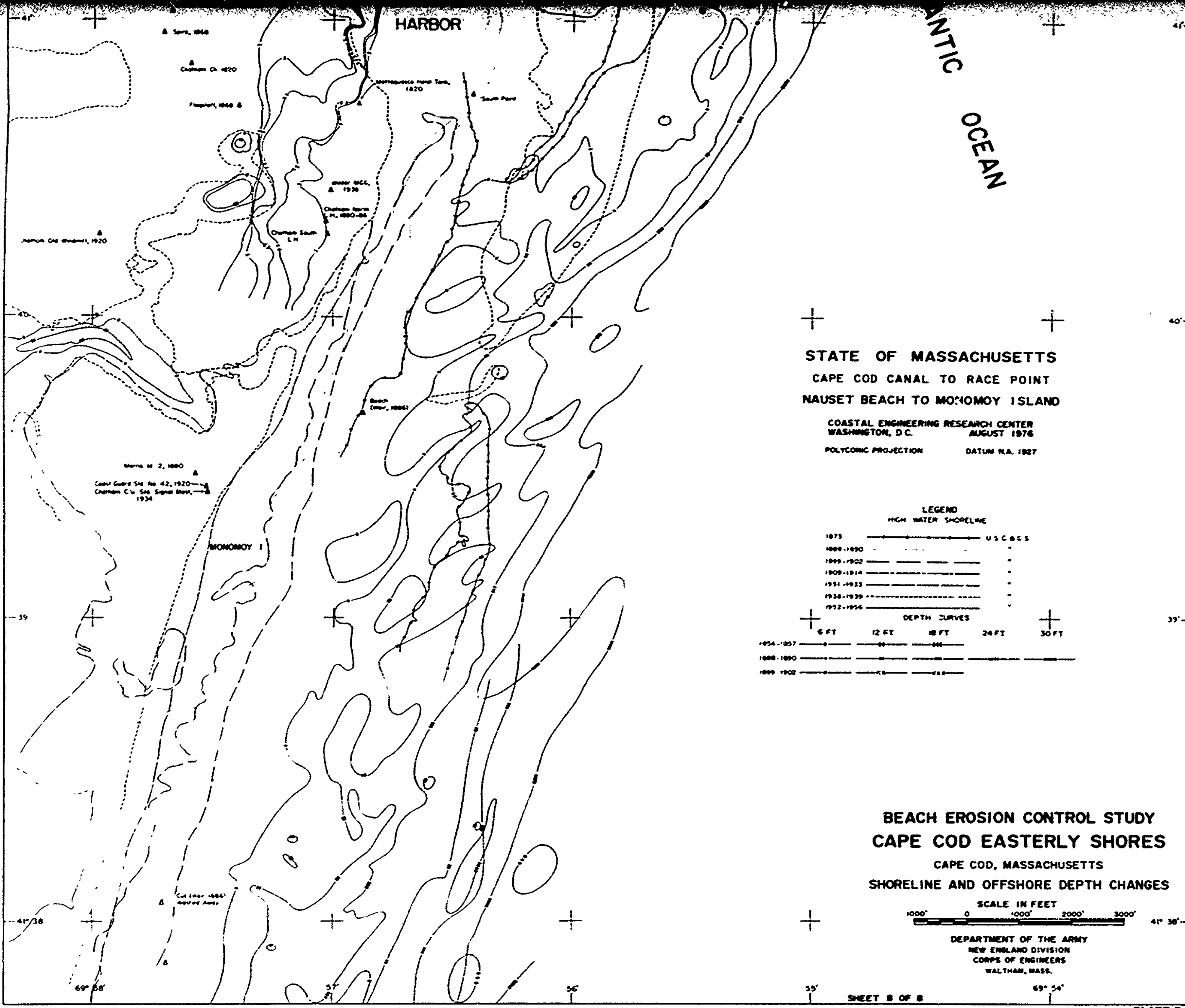

POCHET I
Pochet House Chy, 1909
Coast Guard Sta No 40, 1920
Orleans Coast Guard Sta Signal Mast, 1909
Sampson, 1868
ATLANTIC OCEAN
Nauset Beach
Marsh
NAUSET BEACH
STATE OF MASSACHUSETTS
CAPE COD CANAL TO RACE POINT
NAUSET HARBOR TO NAUSET BEACH
COASTAL ENGINEERING RESEARCH CENTER
WASHINGTON, D.C
AUGUST 1976
POLYCONIC PROJECTION
DATUM N.A. 1927
LEGEND
HIGH WATER SHORELINE
1854-1857
U.S.C.&G.S.
1888-1890
1909-1914
1938-1939
1952-1956
DEPTH CURVES
6 FT
12 FT
18 FT
24 FT
30 FT
1854-1857
1888-1890
BEACH EROSION CONTROL STUDY
CAPE COD EASTERLY SHORES
CAPE COD, MASSACHUSETTS
SHORELINE AND OFFSHORE DEPTH CHANGES
SCALE IN FEET
1000' 0 1000' 2000' 3000'
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.
46
45'
44
41° 43'
69° 57
56'
55'
54'
69° 53'
SHEET 7 OF 8

PLATE D-8



ATLANTIC OCEAN
NAUSET BEACH
CHATHAM HARBOR
41° 43'
42'
41'
69° 53'
55'
56'
57'
69° 58'
Old Stack Chy, 1920
House Chy, 1920
Water Tank, 1934
Chatham Ch Belfry, 1840
Chatham Church Spire, 1846
Spire, 1848
Chatham Ch 1820
Flagstaff, 1868



HARBOR
ANTIC
OCEAN
STATE OF MASSACHUSETTS
CAPE COD CANAL TO RACE POINT
NAUSET BEACH TO MONOMOY ISLAND
COASTAL ENGINEERING RESEARCH CENTER
WASHINGTON, D.C.
AUGUST 1976
POLYCONIC PROJECTION
DATUM N.A. 1927
LEGEND
HIGH WATER SHORELINE
1873
1888-1890
1899-1902
1909-1914
1931-1933
1938-1939
1952-1956
U.S.C.&G.S.
DEPTH CURVES
6 FT
12 FT
18 FT
24 FT
30 FT
1954-1957
1888-1890
1899-1902
MONOMOY I
BEACH EROSION CONTROL STUDY
CAPE COD EASTERLY SHORES
CAPE COD, MASSACHUSETTS
SHORELINE AND OFFSHORE DEPTH CHANGES
SCALE IN FEET
1000'
0
1000'
2000'
3000'
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.
SHEET 8 OF 8
69° 58'
57'
56'
55'
69° 54'
41°
40'
39'
41° 38'

PLATE D-9

SECTION E

INHIBITING EROSION

INHIBITING EROSION

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EFFORTS TO INHIBIT EROSION

Introduction

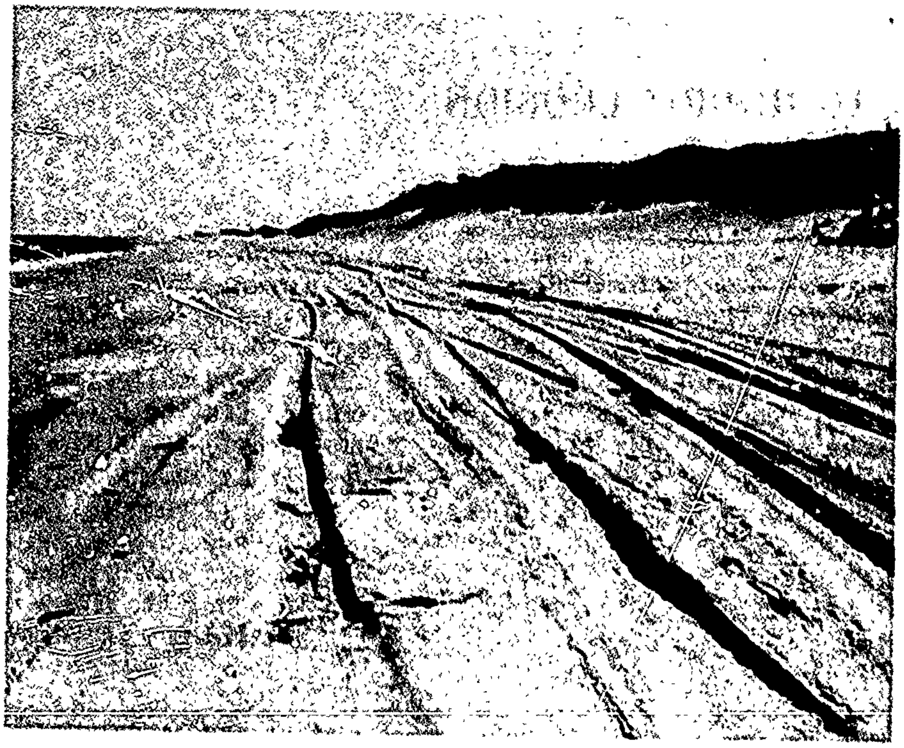
Dunes are common on the northern and southern sections of Cape Cod's outer shores (Figure 1-E1). Formed by natural processes, dunes are maintained by the beach grasses that stabilize the dune surface and collect additional wind-borne sand. Dunes act as natural levees for protecting upland features from wave attack and drifting sand. Dunes also function as reservoirs of sand for replenishing beaches wasted by storms (Knutson, 1977a). When the dunes are cut during storms, the accumulated sand is generally deposited in an offshore bar where it dissipates storm wave energy (U.S. Army Coastal Engineering Research Center, 1975). If moderate weather follows the storm, the offshore bar supplies sand for rebuilding the beach. If, however, the storm breaches the dune, washover channels (Figure 1-E2) may be formed (Knutson, 1977a).

Storms are not the only threat to dunes. Vegetation can be damaged by drought, disease, overgrazing and traffic. A dune with seriously damaged vegetation is vulnerable to wind erosion. A bowl-shaped depression called a blowout may occur on the seaward face of the foredune (Figure 1-E3). If wind and wave action destroy the dune field completely, a barren backshore (Figure 1-E4) may result (Knutson, 1977a).

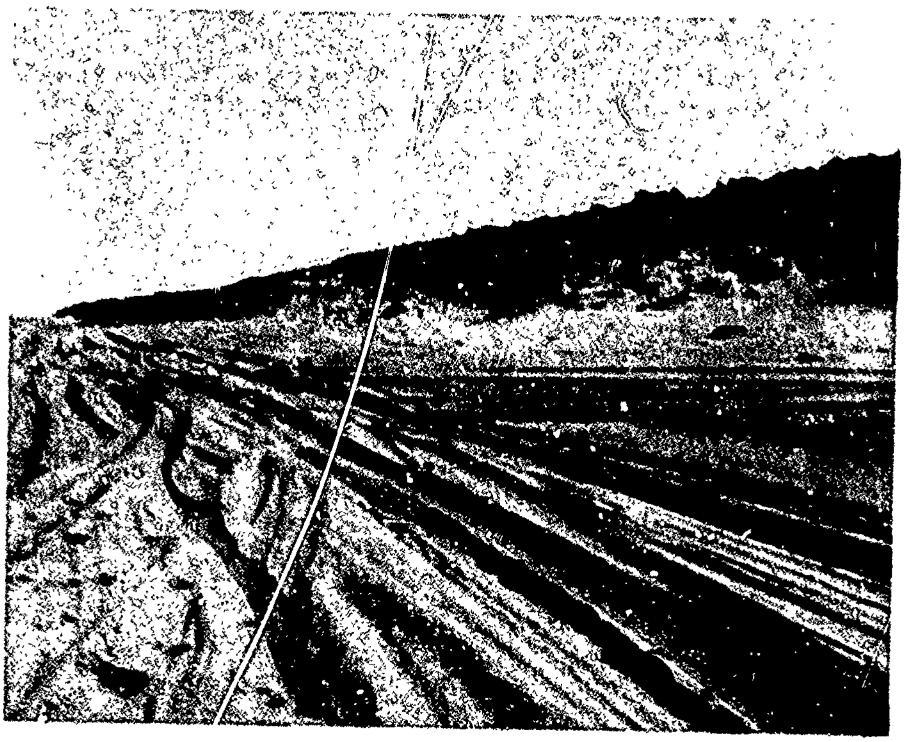
Several protective methods, including sand fencing and beach grass planting, have been tested on Cape Cod. In addition to these nonstructural methods for retarding erosion, a structural attempt at preservation was tried at Coast Guard Beach.

Sand Fencing and Beach Grass Planting

Under natural conditions grasses are the main cause of foredune formation and perpetuation. However, in areas like Cape Cod vegatative foredune formation may not be practical because American beach grass, *Ammophila breviligulata*, is dormant during the main sand-moving period. Therefore, it is necessary to create the incipient dune with fences or other means and later stabilize it with grasses. For details on plants see Appendix 4 of this volume of the report.



Dunes on Nauset Beach at Little Pochet Island (April, 1977)

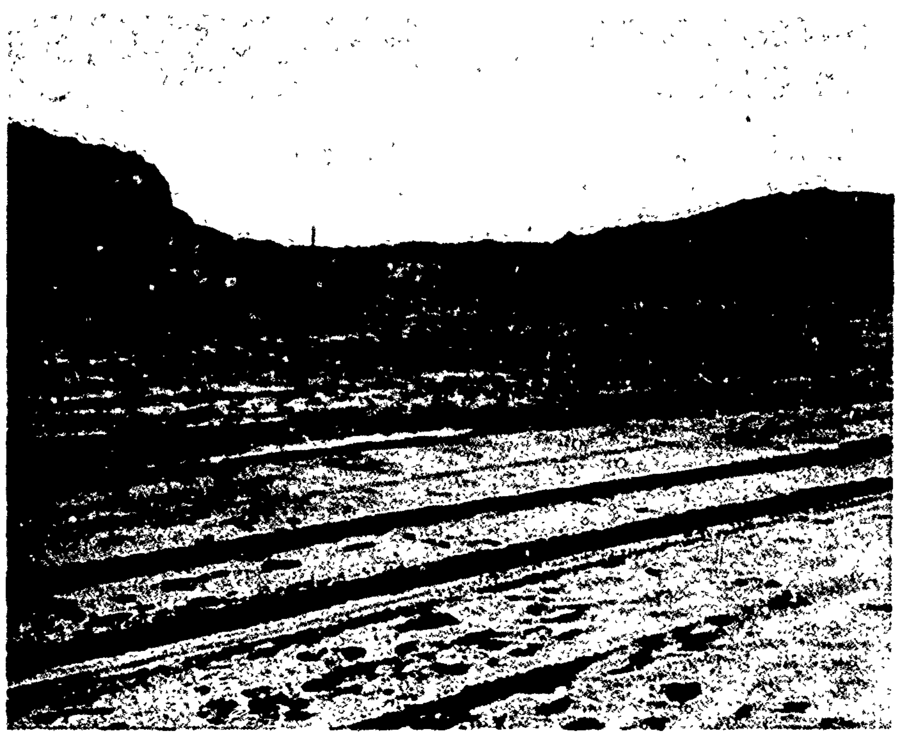


Dunes in Truro, on the beach north of the east end of Pilgrim Lake (April, 1977)

Figure 1-E1. Dunes on Cape Cod

Figure 1-E2. Washover channel (subject to flooding during storms and high water) (Knutson, 1977)

Blowout on Nauset, East of Stony Island
looking from landward side (April, 1977)



Blowout that occurred on Nauset Beach opposite Nauset Bay during the winter of 1976 to 1977, looking from seaward side (April, 1977)

Figure 1-E3. Blowouts on Cape Cod dunes

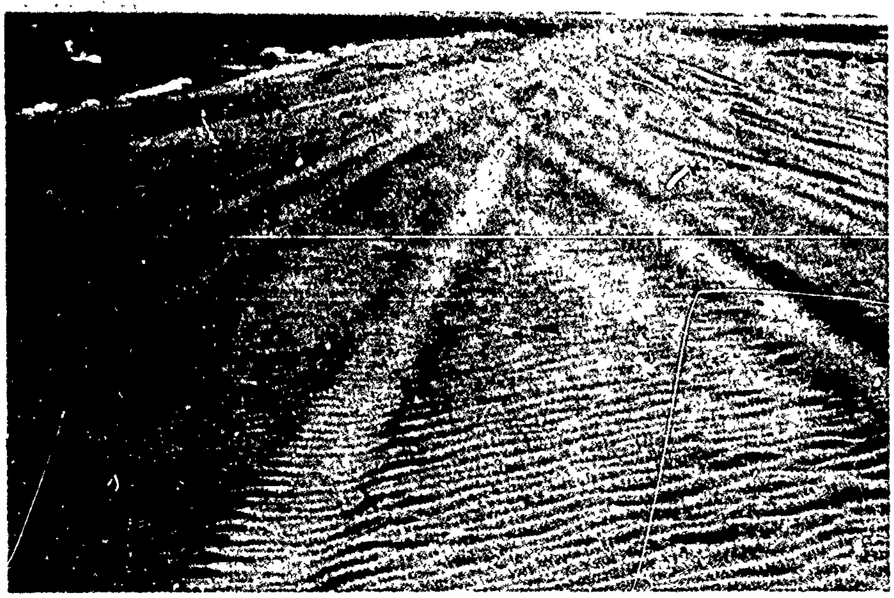


Figure 1-E4. Barren backshore at the tip of Nause Beach (lacks vegetation and sand dunes)

PREVIOUS WORK

Sand fences and beach grass plantings have been used to build coastal dunes in a variety of locations. Dune-building experiments were begun in 1960 by the Beach Erosion Board [now the Coastal Engineering Research Center (CERC)] on the outer banks of North Carolina to determine the most effective sand fence arrangement in that environment. During the first 8 or 9 months after installation, straight fence collected an average of 2.6 cubic yards per linear foot of beach, and straight fence with side spurs collected 1.8 cubic yards per linear foot of beach (Savage, 1962).

American beach grass has been planted experimentally on the coasts of North Carolina and Texas. Plants established in areas devoid of foredunes on Ocracoke Island and Core Banks, North Carolina, trapped an average of 2 cubic yards of sand per linear foot of beach per year over 7 years. When a sufficient supply of sand is available, the initial upward growth of a dune planted with American beach grass in these areas may be as high as 3 to 4 feet per year (Woodhouse and Hanes, 1967). American beach grass was transplanted on Padre Island, Texas, but the plants were not suited to the hot and dry south Texas climate (Dahl et al, 1975).

DUNE BUILDING EFFORT ON CAPE COD

Cape Cod has a history of unstabilized sand areas and the planting of beach grasses to stabilize these areas. Westgate (1904) cites an early use of beach grass (assumed to be American beach grass) in the northern Cape area in 1826. Pratt (1844) cites use of beach grass (again assumed to be American beach grass) prior to 1844 to stabilize areas around Eastham.

Hollick (1902) mentioned the use of European beach grass, Ammophila arenaria, in the Provincetown area, and Westgate (1904) noted that this beach grass was used for extensive reclamation around Provincetown and Truro from 1895 to 1903.

More recent use of American beach grass, Ammophila breviligulata, for stabilization has been cited by Kucinski and Eisenmenger (1943), Zak and Bredekis (1961), and Zak (1961), again, mostly in the Provincetown area.

In the summer of 1963, dunes were constructed with sand fences on the southern part of the Nauset beaches just north of the Old Harbor Life Saving Station by the Massachusetts Beach Buggy Association (MBBA). The fences with side spurs collected sand and prevented waves from cutting a channel into Pleasant Bay (Figure 1-E5) for a couple of seasons, however, the fences were subsequently destroyed.

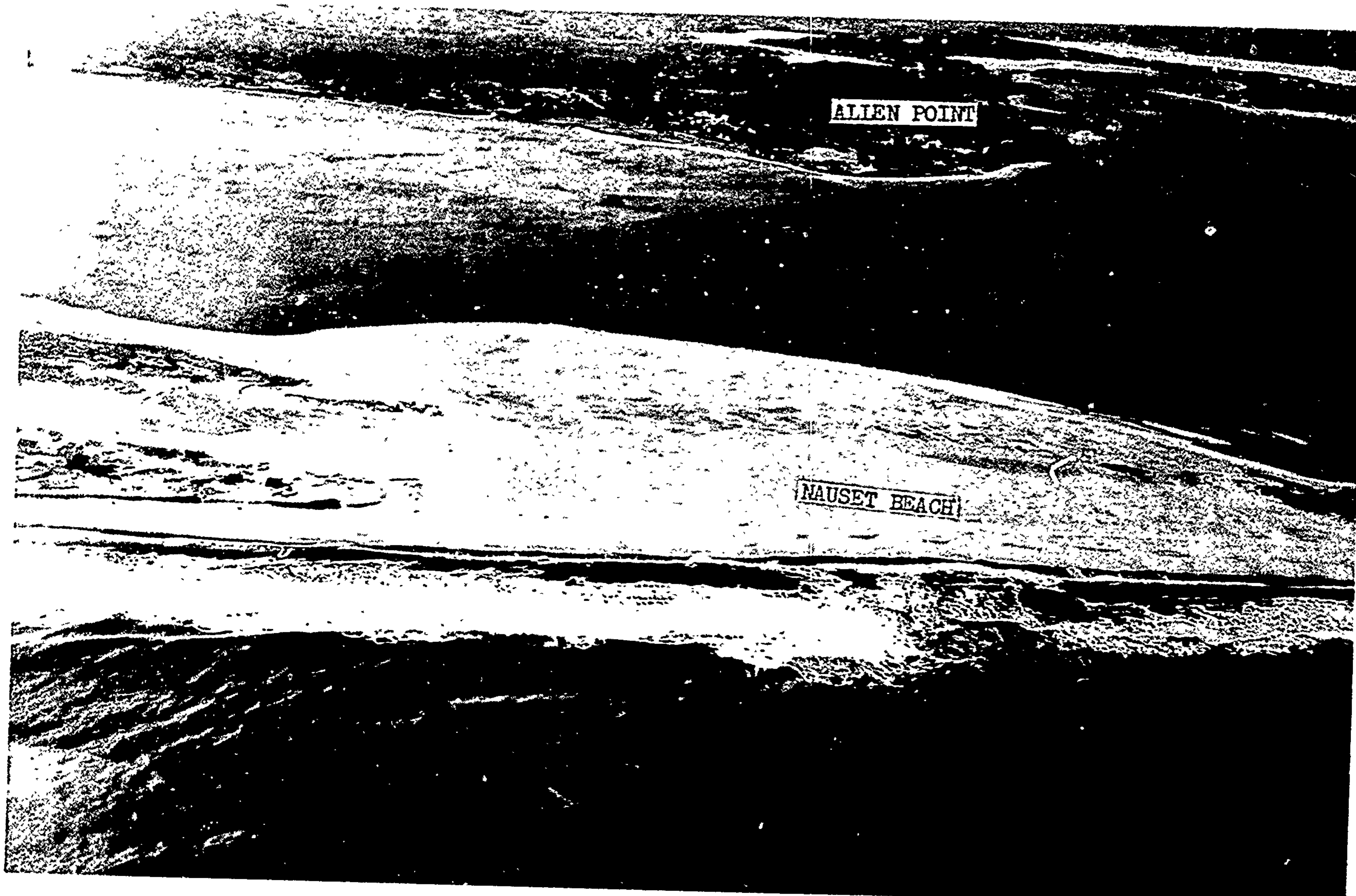


Figure 1-E5. Sand fencing on Nauset Beach, January 1964

During an aerial inspection of the Pleasant Bay area in October 1964, it was observed that Nauset Beach was again being overtopped by storm waves in many places. Large washovers, evident along the entire 8-mile spit from the Orleans Town Beach to Nauset Point, destroyed the continuity of the sand dunes (Figure 1-E6). Some of the washovers were 400 to 600 feet wide and were completely devoid of vegetation; a few were further weakened by beach buggy traffic. During storms, overtopping waves could carry considerable amounts of sand through them into Pleasant Bay. Collectively, the washovers amounted to almost 3 miles of barren sand, and it was evident that the damaged dunes must be restored to prevent shoaling of navigation channels and to protect the valuable shellfish beds in Pleasant Bay.

A pilot dune restoration project was undertaken by the New England Division Corps office in October 1965 for the Pleasant Bay Study with the assistance of the Wellfleet Job Corp. The project consisted of erecting about 1/2 mile of standard snow fence 1 mile north of the abandoned Old Harbor Coast Guard Life Saving Station on Nauset Beach (Figure 1-E7).

The fence was erected in a 2,600-foot line parallel to the beach, about 325 feet back from the high-water line, in an attempt to build the dune forward. Ten-foot spur sections on 50-foot spaces were attached to both sides of the northerly 500 feet of fence. The fencing was supported by 6-foot cedar poles, 4 to 6 inches in diameter, 8 feet apart, and tied securely with twine. The fencing was completed on 20 October 1965.

The sand was building slowly at the fence until a northeast storm, with wind gusts up to 70 miles per hour, hit the area on 9 January 1966. A field inspection made on 9 February 1966 revealed that the southerly section of the fence was destroyed in several places, adding up to a total of 180 feet or about 7 percent. The northerly 500 feet of fencing with 10-foot spur section was almost completely filled to the top of the 4-foot high fence. The estimated amount of sand collected along this section was about 2.6 cubic yards per linear foot. The remaining fence was filled to about 60 percent of the height of the fence, and the amount collected was estimated to be about 2.2 cubic yards per linear foot. The total amount of sand collected for the entire length of fence, excluding the breakthroughs, amounted to about 6,000 cubic yards. Although it was collected over a 2-1/2-month period, the bulk of it accumulated during and right after the one storm. The cost of the fencing and posts was about $1,200. There was no charge to erect the fence because the project was included as a continual training program by the Wellfleet Job Corps. The estimated cost of collecting the sand was $0.20 per cubic yard.

A second row of fencing was erected at the northerly end of the project on 17 August 1966, about two-thirds of the way up the front slope of the new dune and with front spurs only. By 11 January 1967 that fence was almost completely filled (Figure 1-E8). The sand along the remainder of the straight-line fencing without spurs had completely filled to the top and spread over a wide base (Figure 1-E9). By May of 1967 the northerly end of the snow fencing had created an artificial sand dune almost 7 feet high (Figure 1-E10).

Figure 1-E6. Aerial photograph showing washover channels and existing sand fencing, 21 October 1964

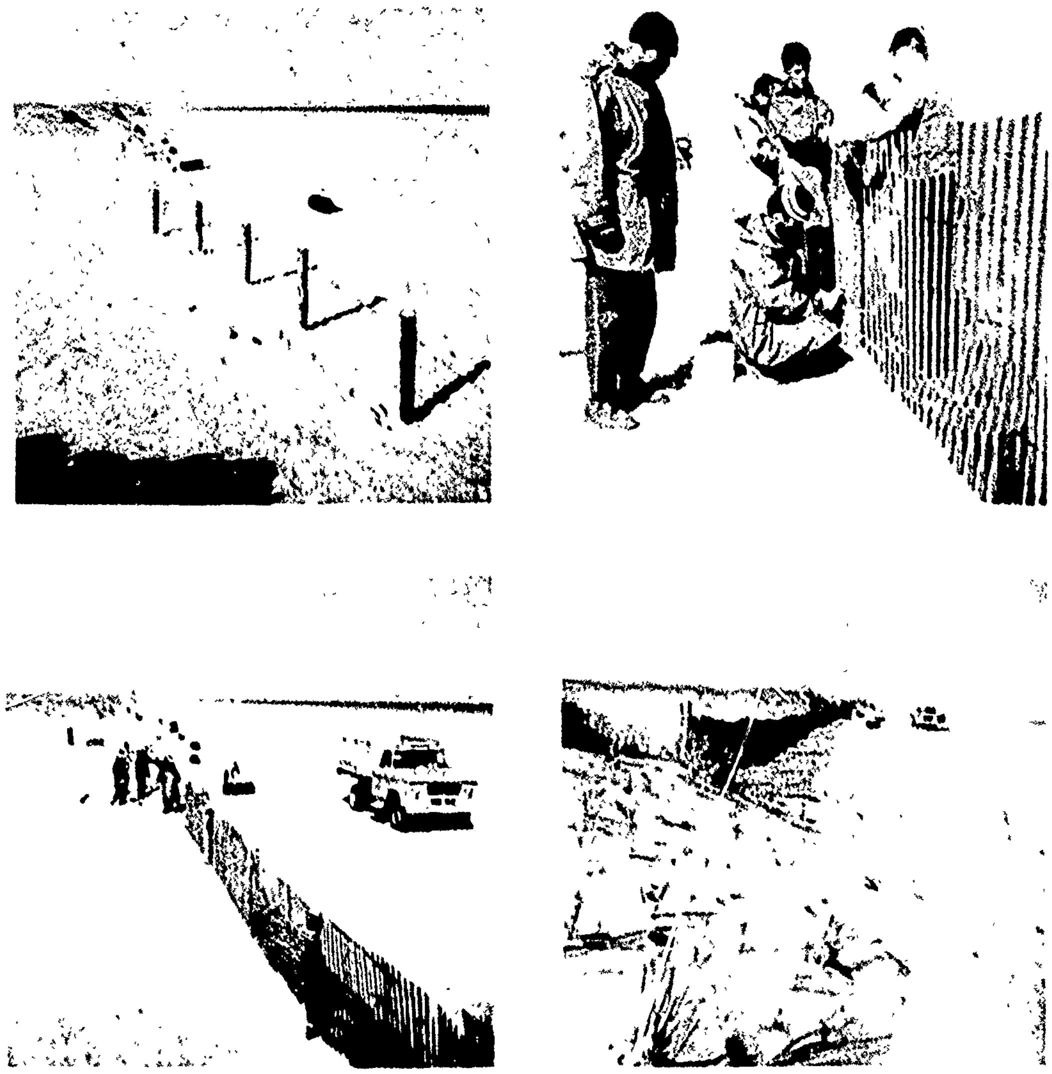


Figure 1-E7. Snow fence project, 6 October 1965 (Installation of snow fence on Nauset Beach by Wellfleet Job Corps personnel. Photos by Corps of Engineers)

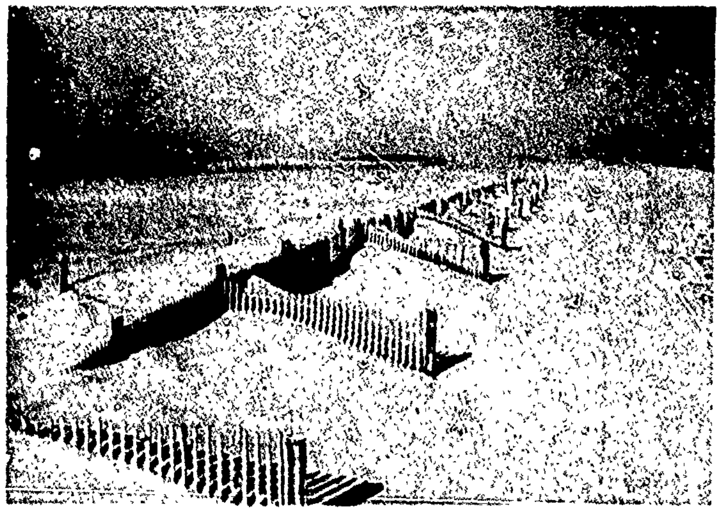


Figure 1-E8. Sand fencing with spurs on Nauset Beach, 11 January 1967

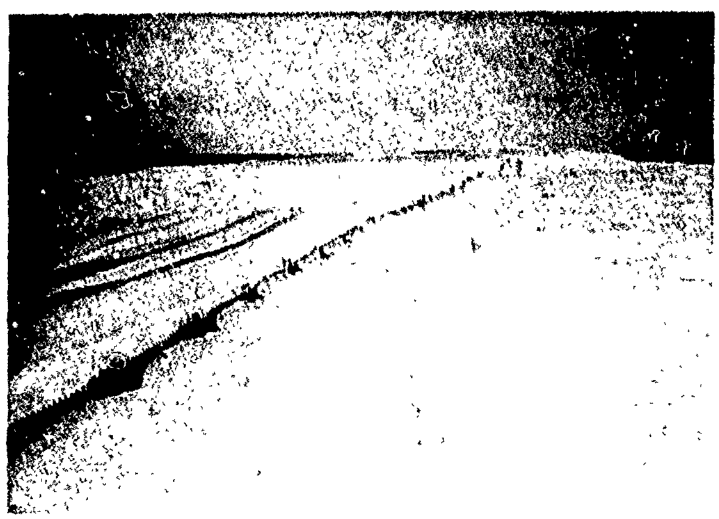


Figure 1-E9. Straight sand fencing on Nauset Beach, 11 January 1967

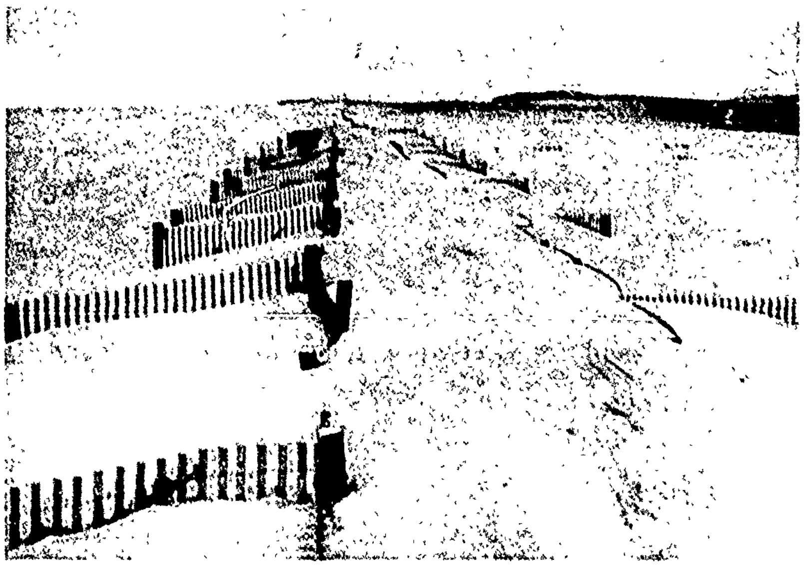


Figure 1-E10. Sand fencing on Nauset Beach, 5 May 1967

The use of sand fencing on Nauset Beach retarded wind erosion of the beach and built dunes that prevented waves from overtopping the barrier beach.

An experimental dune building project was begun by CERC in May 1969 at the end of Nauset Spit at the north side of Nauset Harbor inlet in Eastham, Massachusetts. Nauset Harbor is connected with the sea by a migrating inlet. The inlet is bounded on the north and south by spits that are constantly changing in response to erosion, accretion and storm influence. From 1856 until 1940 the inlet opened at the south end of the harbor near Nauset Heights. Then, in 1941 the spit grew northward against the littoral drift and the inlet shifted approximately 1 mile to the north (Zeigler, 1960). During December 1957, the tip of the south spit was removed by wave action, and subsequent erosion by winter storms further reduced its length from approximately 4,050 feet on 21 October 1957 to 1,850 feet on 10 April 1958 (Zeigler, 1958). By 1969 the south spit was approximately 2,800 feet long and the inlet was migrating north.

The experimental dune building area was divided into nine 400-foot sections, consisting of American beach grass, straight sand fence, sand fence with side spurs and fabric fence. During the first year of the experiment, Nauset Harbor inlet migrated north and destroyed one of the fence sections. The grasses planted in May did not survive due to lack of moisture and the fences unevenly accumulated the sand. Thus, no conclusions could be drawn from a comparison of the sections of beach grass and sand fencing. The inlet continued to migrate north, and it was believed that the remaining experimental sections would eventually wash away.

In April 1970 the site in Eastham was abandoned, and another experimental site was selected on the sand spit on the south side of Nauset Harbor inlet in Orleans. CERC conducted more dune building experiments on this south spit between 1970 and 1974 (Knutson, 1977b). The experiments tested the sand trapping ability of American beach grass (Ammophila breviligulata) straight sand fence and sand fence with side spurs. They modified the design of the original experiment and established five 500-foot sections approximately parallel to the beach in a north-south line. A baseline survey of the site made on 23 April 1970 consisted of ten irregularly spaced profiles (two in each section). American beach grass was planted in the first, third and fifth sections on 18-, 24- and 36-inch centers, respectively, in April 1970, with remedial plantings taking place intermittently throughout the study.

Sand fence with spurs every 50 feet was installed in section 2 and a single straight run of sand fence was installed in section 4. As the sand accumulated and the existing fencing was buried, new sections of fence were added parallel to the original fence; the first sections were added on 21 April 1970, the second on 4 January 1971 and the rest on 14 and 15 February 1972. In April 1972 the dunes formed by the fences were planted with a variety of vegetation for stabilization.

During the 4-year study (1970-74), sand accumulated in all sections at an average volume of 6.0 cubic yards per linear foot. However, there were differences in the total sand accumulations and the rate at which the sand accumulated. Figure 1-E11 shows the average sand accumulation with time. The number of stations with each type of fence or grass are indicated on the figure.

The most successful section was the one with straight sand fencing stabilized by beach grass (7.9 cubic yards per linear foot). Straight sand fencing also produced the most rapid initial accumulations.

Beach grass without any fencing showed the smallest accumulations at the start of the experiment. However, at the end of the second year, the rate of accumulation increased, and the final volume of sand, although less, was still substantial (5.5 cubic yards per linear foot).

Sand fencing with spurs created a high initial accumulation of sand but subsequent growth was slower. Eventually, some of the accumulated sand was lost and the final volume (3.8 cubic yards per linear foot) was the smallest for the three methods of dune stabilization. However, these results may not be representative because sand fencing with spurs was installed at two locations and the results at the two stations were markedly different. One of the stations produced a large accumulation (5.5 cubic yards per linear foot) while volume at the other station was much less (2.0 cubic yards per linear foot). Therefore, the average for these stations (3.8 cubic yards per linear foot) may not adequately represent the sand-trapping capability of fencing with spurs.

It can be concluded that more sand was accumulated by the combination of straight sand fences and vegetation than by vegetation alone during the 4-year period. Because beach grass initially collected sand slowly, Figure 1-E11 may reflect the time required for the beach grass to become established before it can accumulate substantial amounts of sand.

Secondly, it can be concluded that the addition of spurs to fences is not merited as there is no appreciable advantage derived and the cost of the fences is increased.

These results indicate that significant volumes of sand can be accumulated and retained by use of non-structural means such as sand fencing and beach grass planting. In areas such as the south spit at Nauset, these preservation techniques have proved to be practical and effective.

Intsilation of Rubble Mound at Coast Guard Beach

In the structural experiment, a total of 10,000 cubic yards of rubble was placed in front of the parking lot on Coast Guard Beach from 1966 to

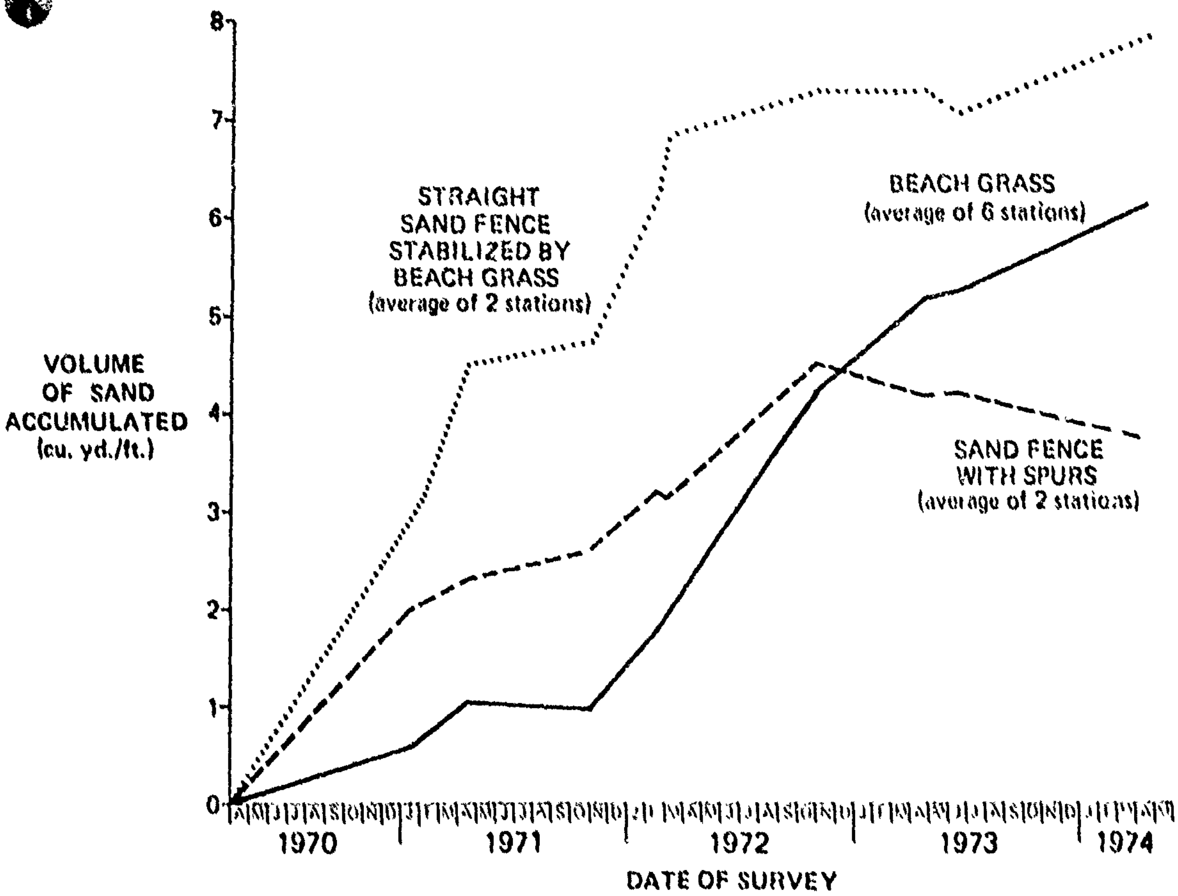


Figure 1-E11. Sand accumulation with time for dune restoration project of the south spit at the inlet to Nauset Harbor

1972 in an attempt to slow erosion. It became apparent that the rubble was actually accelerating erosion in adjacent areas and the jagged edges of the rubble had become a hazard to swimmers (Figure 1-E12). By the fall of 1976 the rubble was removed.

SHORELINE PREDICTIONS

In an effort to assist local communities and government agencies in planning the siting of structures, attempts were made to project the changes in the outer Cape Cod shoreline for the next 50 years. To make these estimates, existing erosion/accretion data and historical shoreline changes were reviewed, and predictions based on the University of Rhode Island wave refraction analysis (Section C of this Appendix) were made.

After carefully reviewing the U.S. Army Corps of Engineers shoreline-changes maps, it was concluded that predicting the future shape of the outer Cape Cod shoreline from historical charts was not possible. For the greater portion of the shore available data showed no definite trends. In addition, the seasons during which the surveys were made and the techniques employed were highly variable, making comparisons extremely difficult.

Probably the most useful basis available for predicting shoreline changes for the outer Cape Cod area is the work of Zeigler et al (1964). Using a series of transects from Nauset Spit to Pilgrim Lake, Zeigler and his fellow scientists reoccupied Marindin's stations during 1957 and 1958. (See Section D of this Appendix) From these two sets of carefully controlled measurements, Zeigler et al (1964) estimated the advance and retreat of the shoreline in the study area. The results of this work show a general erosion of the shoreline on the order of 2.6 feet per year from Nauset Spit to the Pilgrim Lake area. Between the Pilgrim Lake area and Race Point the erosion rate drops, passes through zero and changes to net accretion. A detailed plot (Figure 1-E13) taken from Zeigler's paper shows this trend.

Figure 1-E12. Ruddle in place at Coast Guard Beach,
2 June 1967

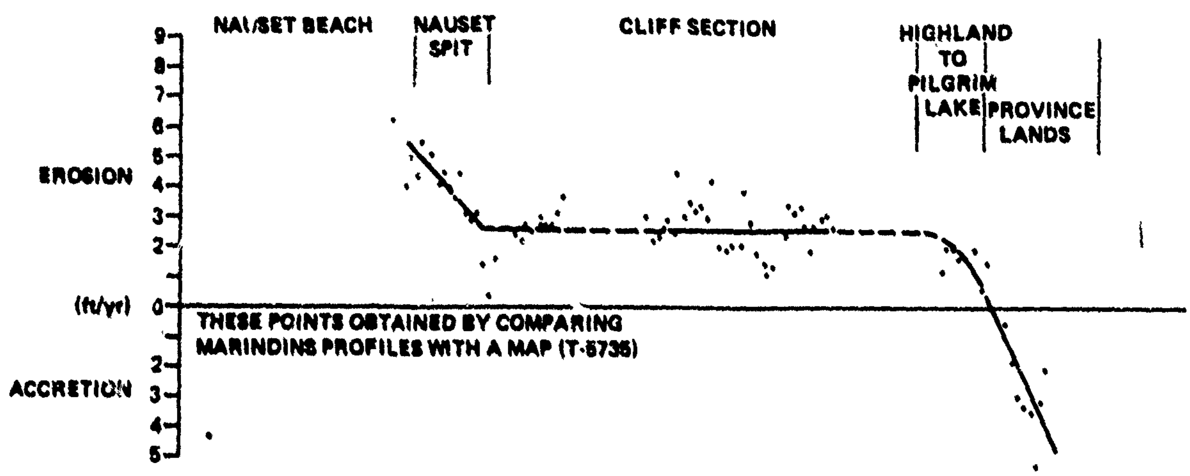


Figure 1-E13. Rate of erosion of east coast of Cape Cod determined by comparing profiles measured in 1887 by Marindin and same profiles measured in 1957-58 (After Zeigler et al, 1964)

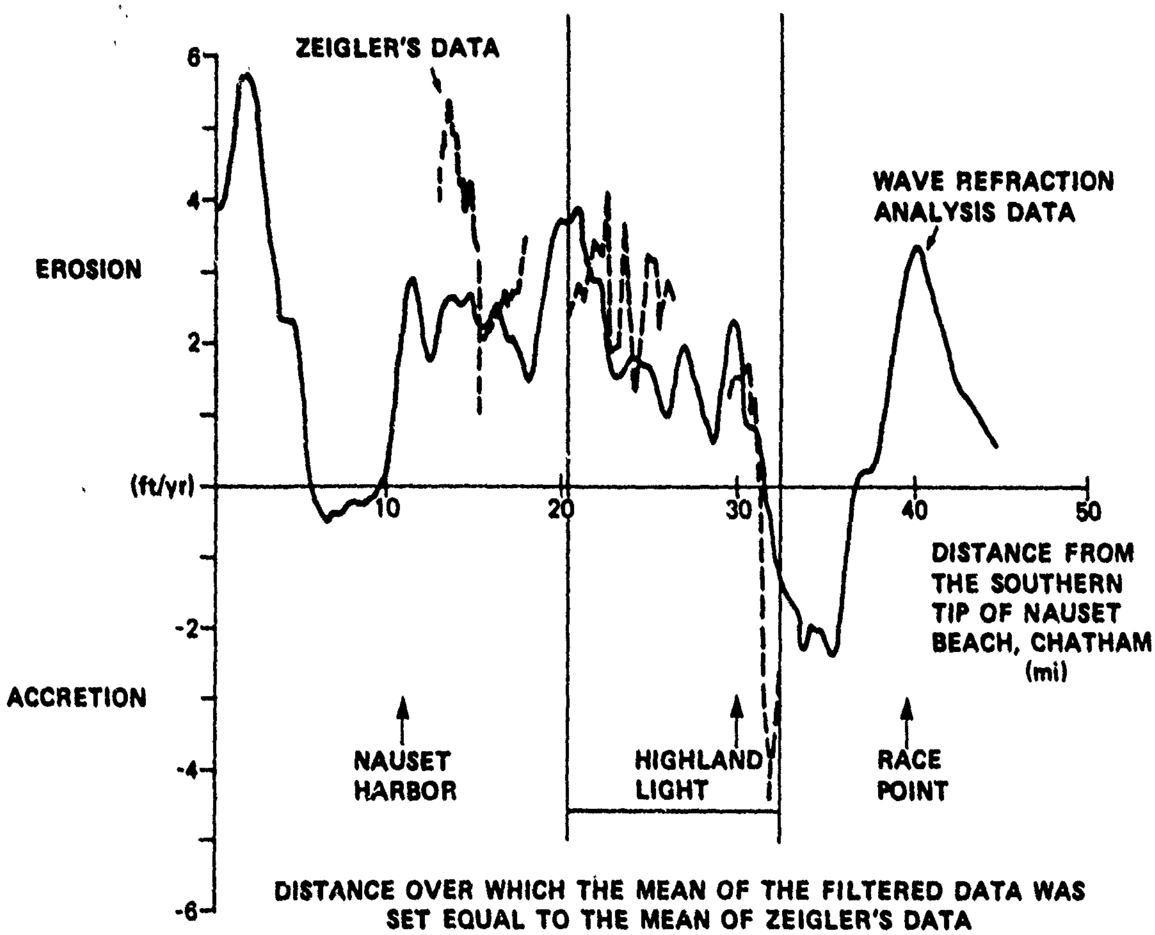


Figure 1-E14. Comparison of erosion/accretion rates determined by Zeigler et al (1964) and URI wave refraction analysis

Figures 1-E14 through 1-E17 show the yearly changes in the shoreline predicted by the wave refraction program and plotted against the Cape Cod coastline. As these figures show, the wave refraction analysis predicts that the coast from Chatham to Highland Light is eroding (with one area of accretion south of Nauset Harbor). Near Head of the Meadow Beach (32-mile mark), the trend changes from erosion to accretion, and accretion predominates from the 32-mile mark westward to near the Race Point Coast Guard Station. From this location to Herring Cove Beach, erosion is predicted.

While these estimates will not be particularly useful for predicting small-scale features or changes near complicated inlet geometries such as Nauset Harbor inlet, they do provide the basis for reasonable estimates of the general trend of shoreline change. To predict the shoreline in the future one simply multiplies the erosion/accretion rate by the number of years of interest and obtains the new shoreline position (Figure 1-E18).

According to the prediction the eastern shoreline of Cape Cod will lose at least 50 feet in most areas during the next 50 years. Exceptions will occur in the area of North Truro and Provincetown (32-mile mark to 37-mile mark) where the coast may grow seaward by 100 feet or more. Erosion for most of the region from Nauset Harbor inlet to Highland Light is predicted to exceed 100 feet during the next 50 years. Erosion of 150 feet is expected near LeCount Hollow Beach (20-mile mark). Structures located in these areas will have to be moved, and further construction in the threatened zone should be prohibited.

The approximate change in the location of the mean high water line along the easterly shore of Cape Cod for the 50-year life of the project is based on following background data:

a. Aerial photographs (CRREL)
b. Wave refraction Analysis (URI)
c. Shoreline change maps (CERC)

This mean high water line varies annually from season to season and is the approximate location that can be anticipated in the year 2029 (Table 1-E1). This approximation of the predicted mean high water line is not particularly accurate at inlets or south of Nauset inlet and therefore these areas are omitted from the table. The assumption is made that the top of bank, bluff or dune will also erode proportionally to the approximate rate predicted. This will vary in areas where geological stratification of different types of material becomes prevalent.

The reference points on the predicted ocean high water line are located on maps A, B, C, D and E.

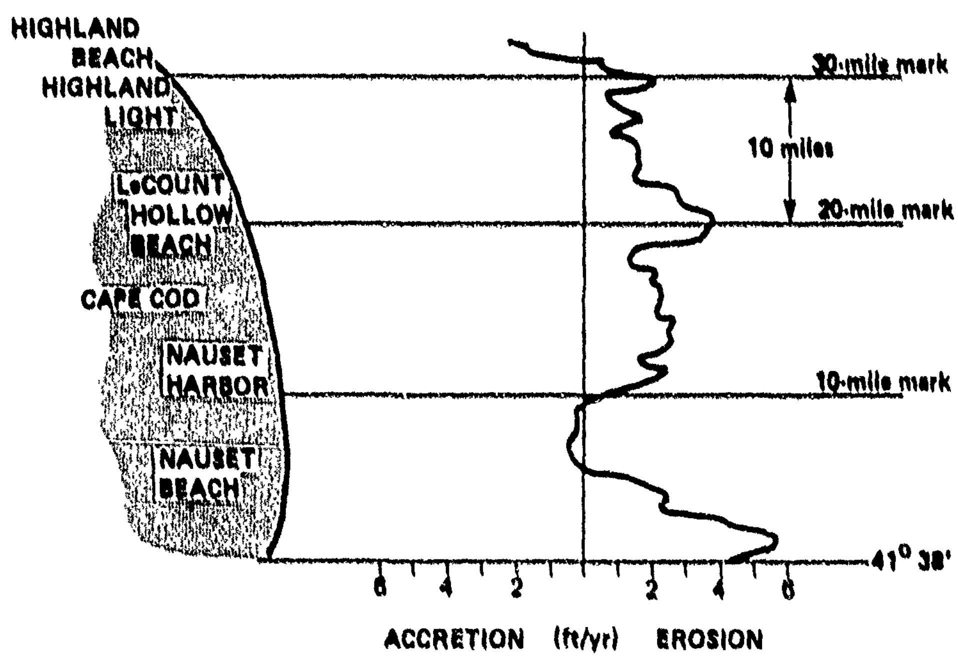


Figure 1-E15. Yearly shoreline changes for the easterly shores of Cape Cod from the southern tip of Nauset Beach, Chatham, to Highland Beach, Truro, predicted by wave refraction analysis

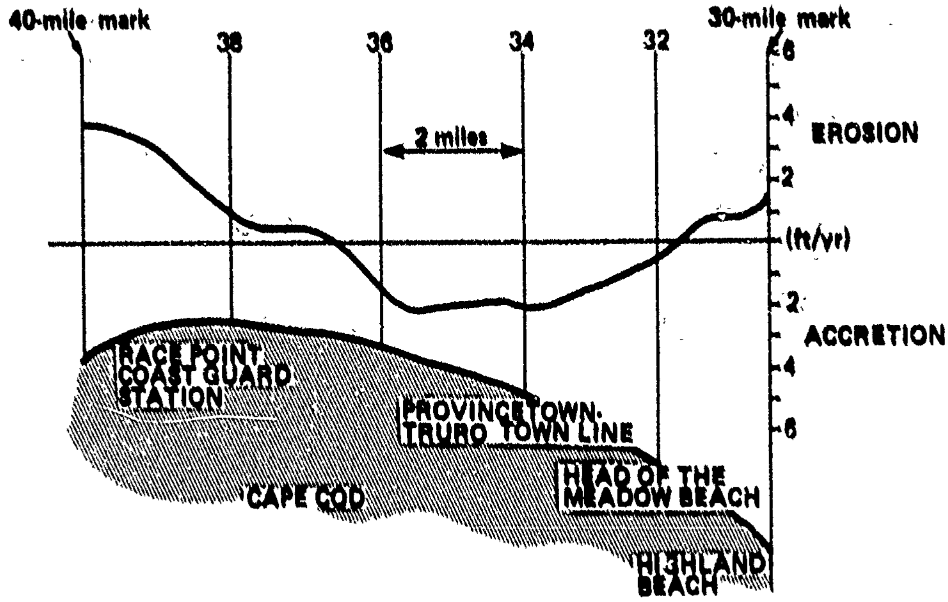


Figure 1-E16. Yearly shoreline changes for the shores of Cape Cod from Highland Beach, Truro, to Race Point, Provincetown, predicted by wave refraction analysis

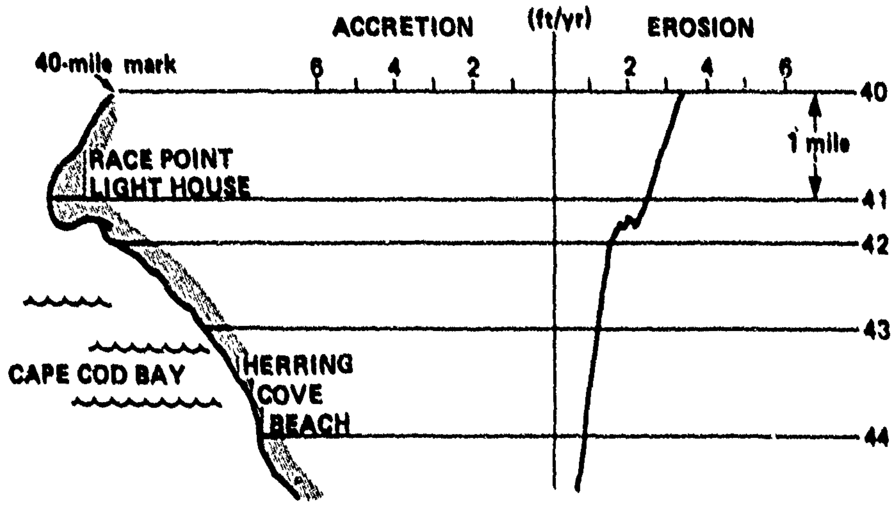


Figure 1-E17. Yearly shoreline changes for the shores of Cape Cod from Race Point to Herring Cove Beach, Provincetown, predicted by wave refraction analysis

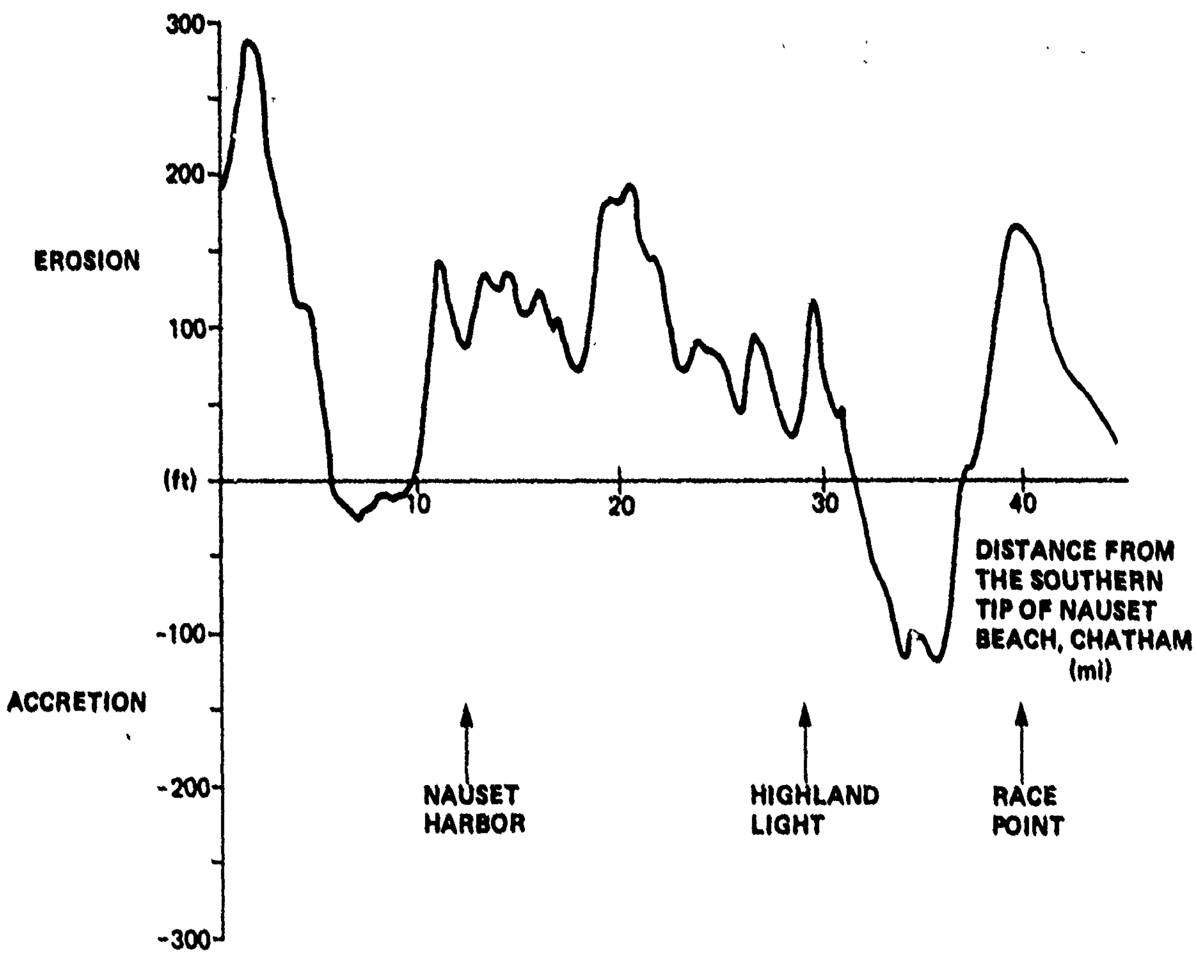


Figure 1-E18. Fifty-year shoreline prediction based on wave refraction analysis

Table 1-E1. The Average Approximate Location of the Mean High Water Line and/or Top of Bank or Dune Anticipated by the Year 2029 (Cont'd)

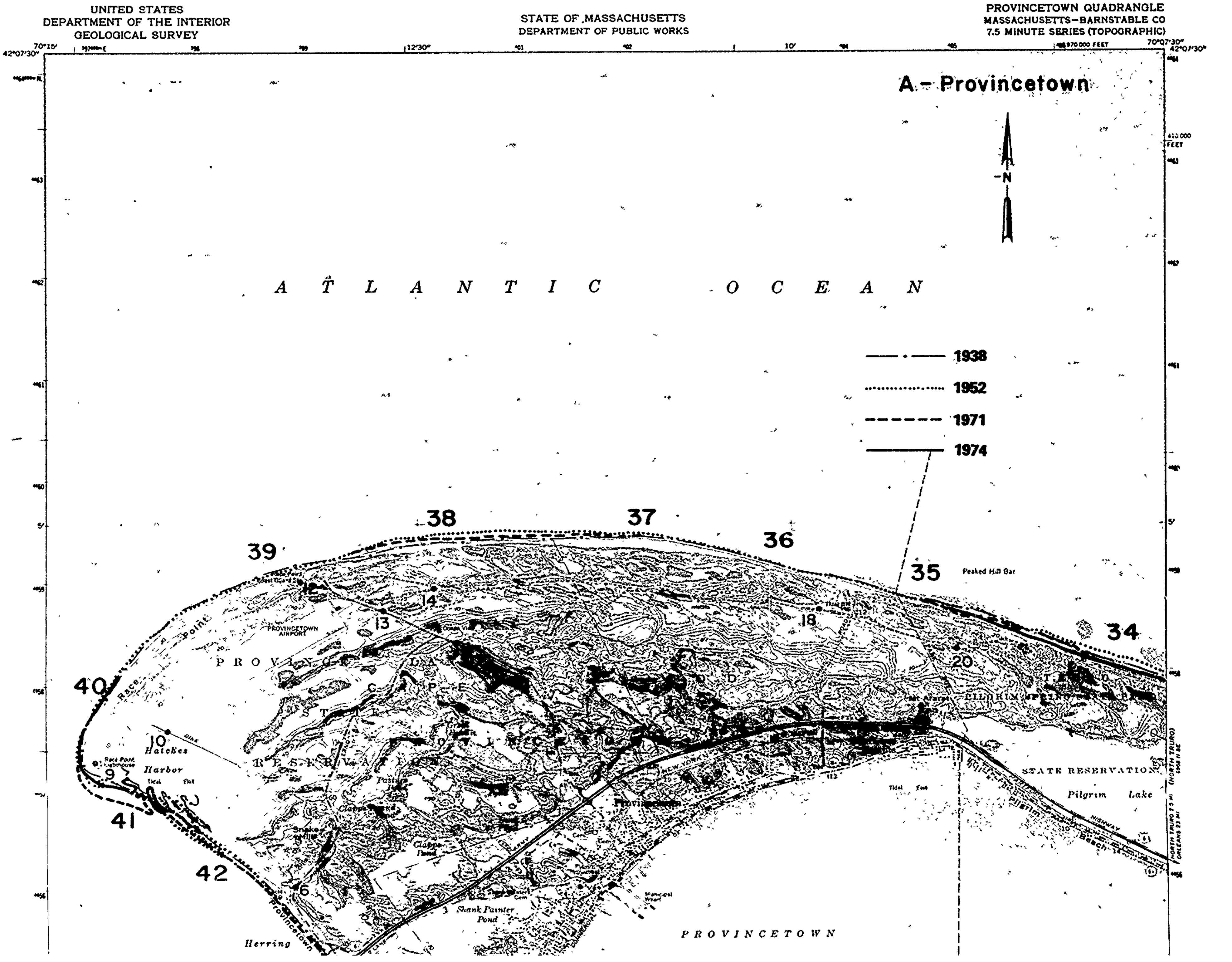
[1]REFERENCE POINT	COMMENTS	[2]TOTAL DISTANCE MOVED BETWEEN 1979-2029
0-7	EROSION	No prediction made in this dynamic area
8	"	150
9	"	150
10	"	150
11	"	125
12	"	No prediction made in this dynamic area
13	"	100
14	"	100
15	"	100
16	"	125
17	"	100
18	"	150
19	"	100
20	"	100
21	"	100
22	"	100
23	"	150
24	"	125
25	"	150
26	"	125
27	"	100
28	"	100
29	"	125
30	"	150
31	"	200
32	"	150
33	"	100
34	"	75
35	ACCRETION	75
36	"	125
37	"	150
38	"	150
39	"	150
40	"	125

Table 1-E1. The Average Approximate Location of the Mean High Water Line and/or Top of Bank or Dune Anticipated by the Year 2029

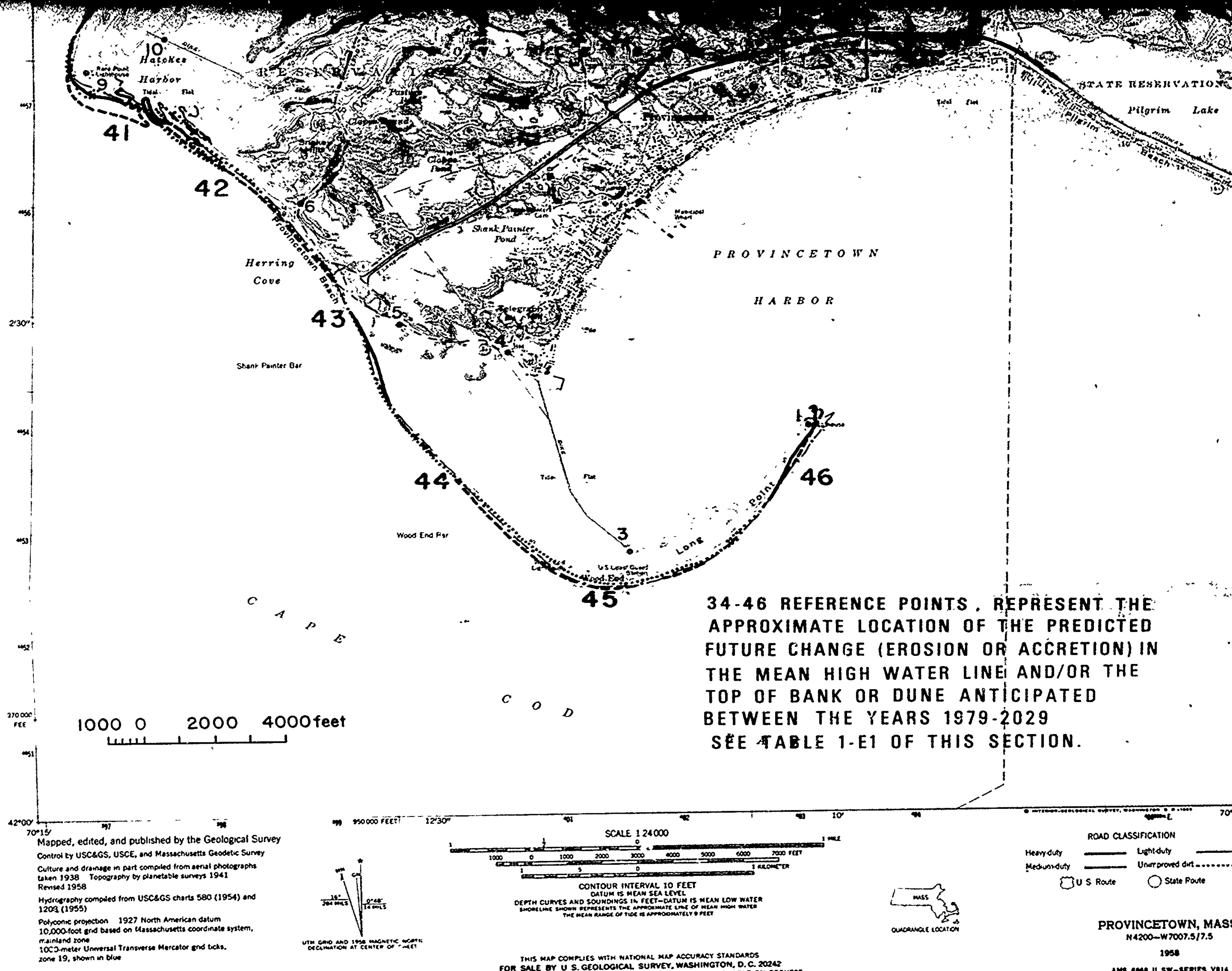
[1]REFERENCE POINT	COMMENTS	[2]TOTAL DISTANCE MOVED BETWEEN 1979-2029
41	EROSION	No prediction made in this dynamic area
42	"	50
43	"	75
44	"	75
45	"	100
46	"	No prediction made in this dynamic area

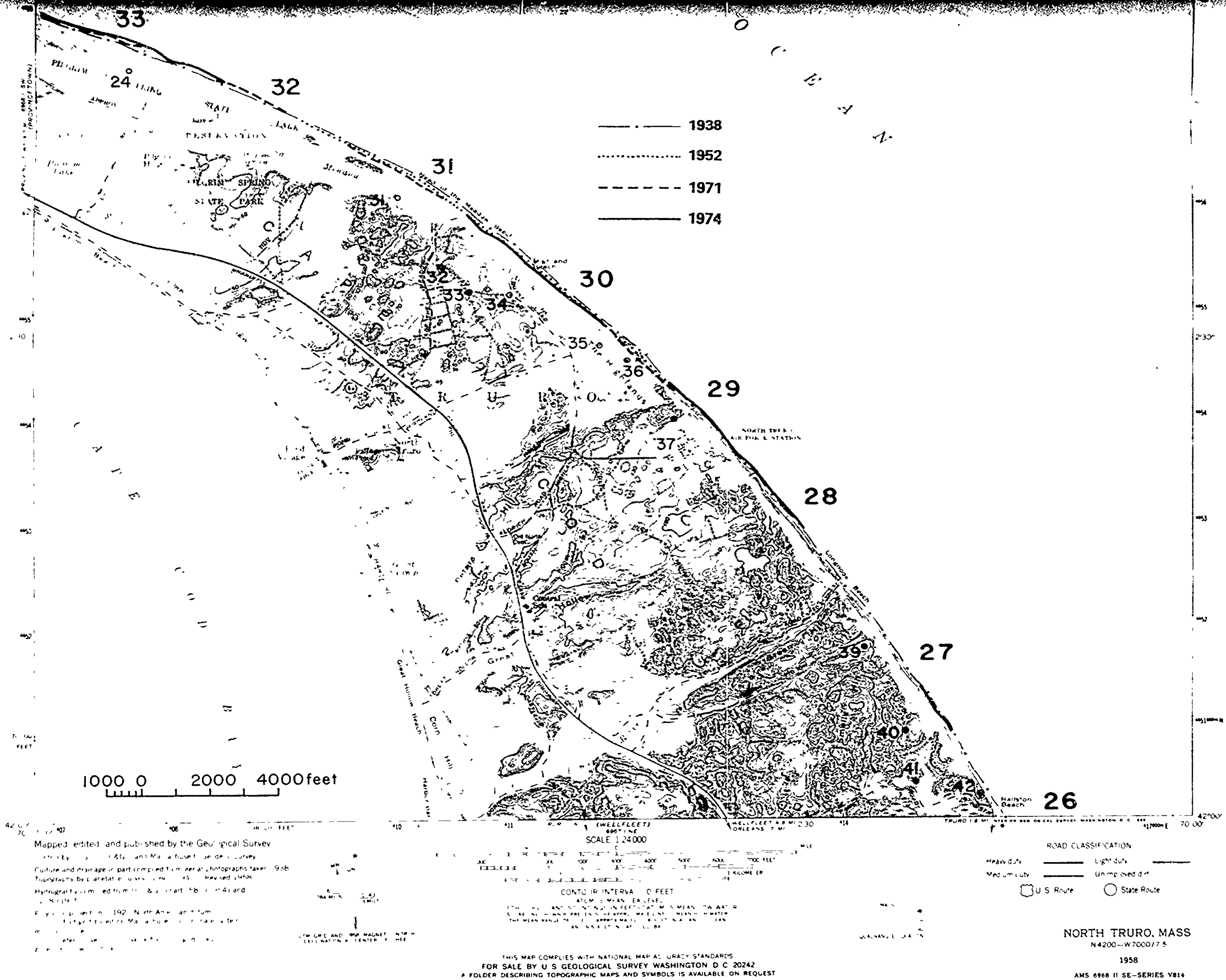
[1]See Drawings A through E.

[2]This is a rough approximation and can vary with the seasons and could change from year to year depending upon intensity, magnitude and duration of storms and weather patterns.

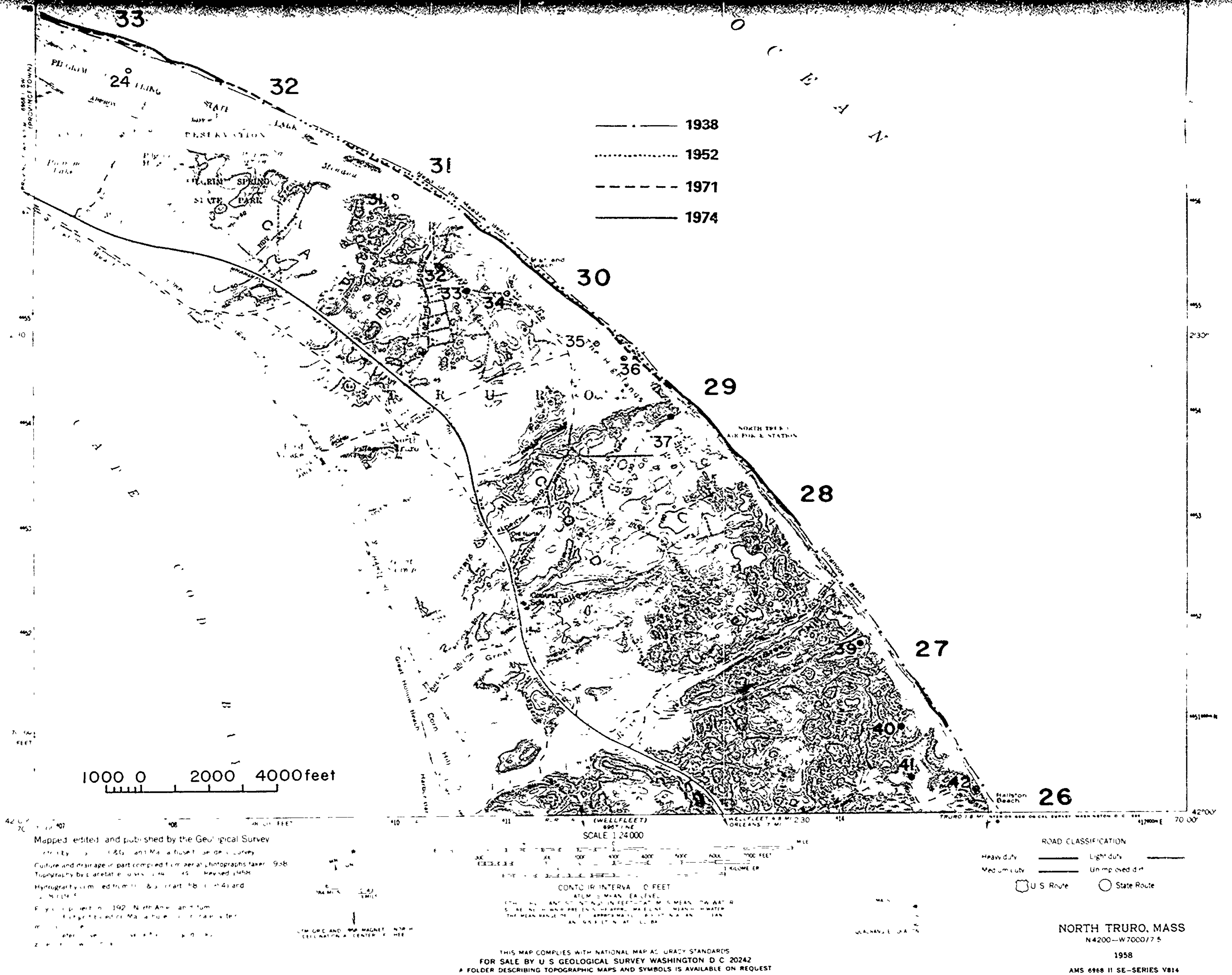


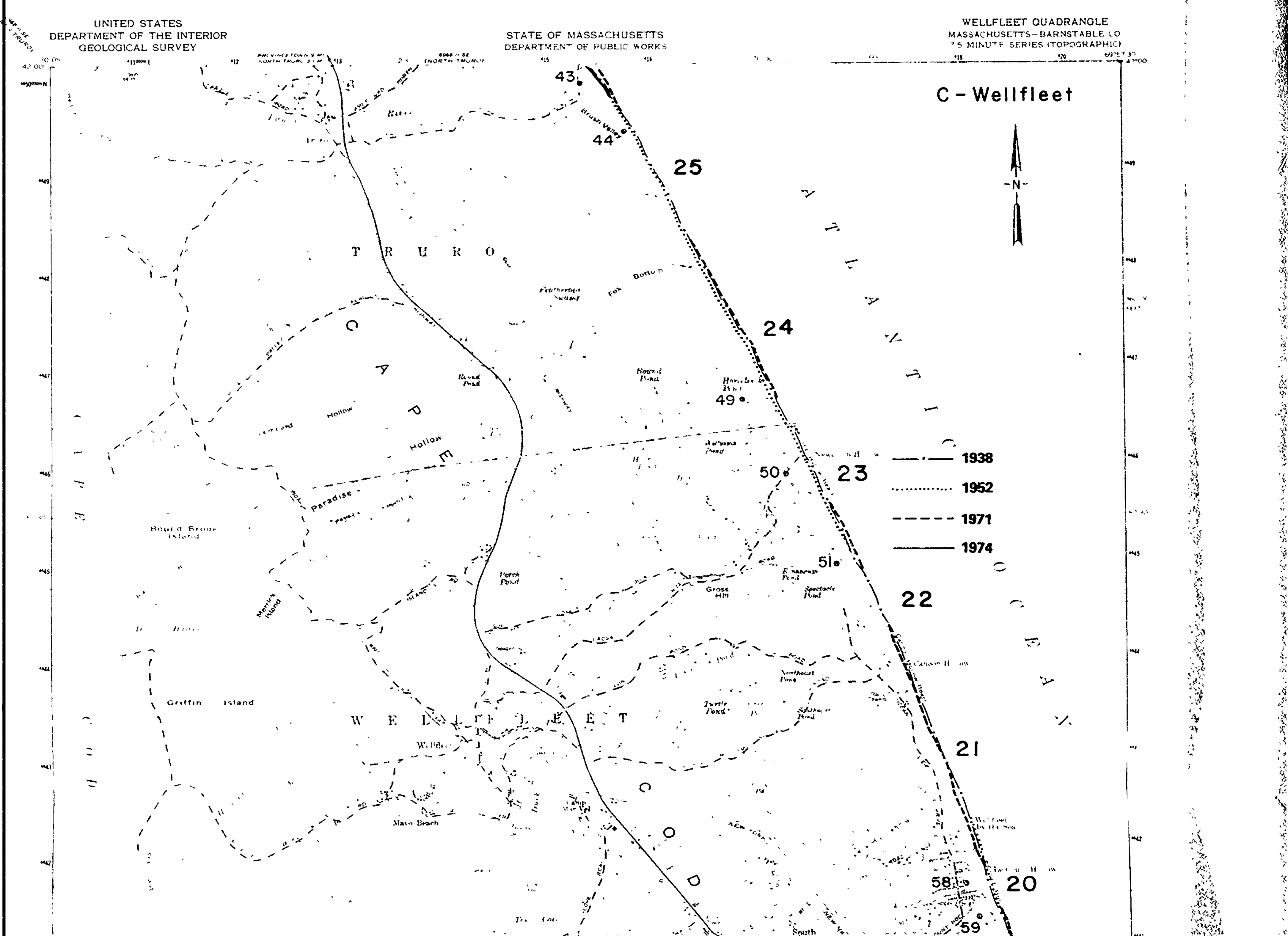
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
STATE OF MASSACHUSETTS
DEPARTMENT OF PUBLIC WORKS
PROVINCETOWN QUADRANGLE
MASSACHUSETTS–BARNSTABLE CO
7.5 MINUTE SERIES (TOPOGRAPHIC)
A – Provincetown
N
ATLANTIC OCEAN
1938
1952
1971
1974
Peaked Hill Bar
34
35
36
37
38
39
40
41
42
PROVINCETOWN AIRPORT
Race Point
Hatches Harbor
Pilgrim Lake
STATE RESERVATION
Shank Painter Pond
Herring
PROVINCETOWN


34-46 REFERENCE POINTS, REPRESENT THE APPROXIMATE LOCATION OF THE PREDICTED FUTURE CHANGE (EROSION OR ACCRETION) IN THE MEAN HIGH WATER LINE AND/OR THE TOP OF BANK OR DUNE ANTICIPATED BETWEEN THE YEARS 1979-2029
SEE TABLE 1-E1 OF THIS SECTION.
41
42
43
44
45
46
PROVINCETOWN
HARBOR
CAPE COD
Herring Cove
Hatches Harbor
Provincetown Beach
Shank Painter Bar
Shank Painter Pond
Wood End Flat
Long Point
STATE RESERVATION
Pilgrim Lake
1000 0 2000 4000 feet
Mapped, edited, and published by the Geological Survey
Control by USC&GS, USCE, and Massachusetts Geodetic Survey
Culture and drainage in part compiled from aerial photographs taken 1938 Topography by planetable surveys 1941
Revised 1958
Hydrography compiled from USC&GS charts 580 (1954) and 1203 (1955)
Polyconic projection 1927 North American datum
10,000-foot grid based on Massachusetts coordinate system, mainland zone
1000-meter Universal Transverse Mercator grid ticks, zone 19, shown in blue
UTM GRID AND 1958 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET
SCALE 1:24000
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
DEPTH CURVES AND SOUNDINGS IN FEET—DATUM IS MEAN LOW WATER
SHORELINE SHOWN REPRESENTS THE APPROXIMATE LINE OF MEAN HIGH WATER
THE MEAN RANGE OF TIDE IS APPROXIMATELY 9 FEET
THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, WASHINGTON, D. C. 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST
QUADRANGLE LOCATION
ROAD CLASSIFICATION
Heavy-duty
Light-duty
Medium-duty
Unimproved dirt
U S Route
State Route
PROVINCETOWN, MASS.
N4200—W7007.5/7.5
1958
AMS 6968 II SW—SERIES V814

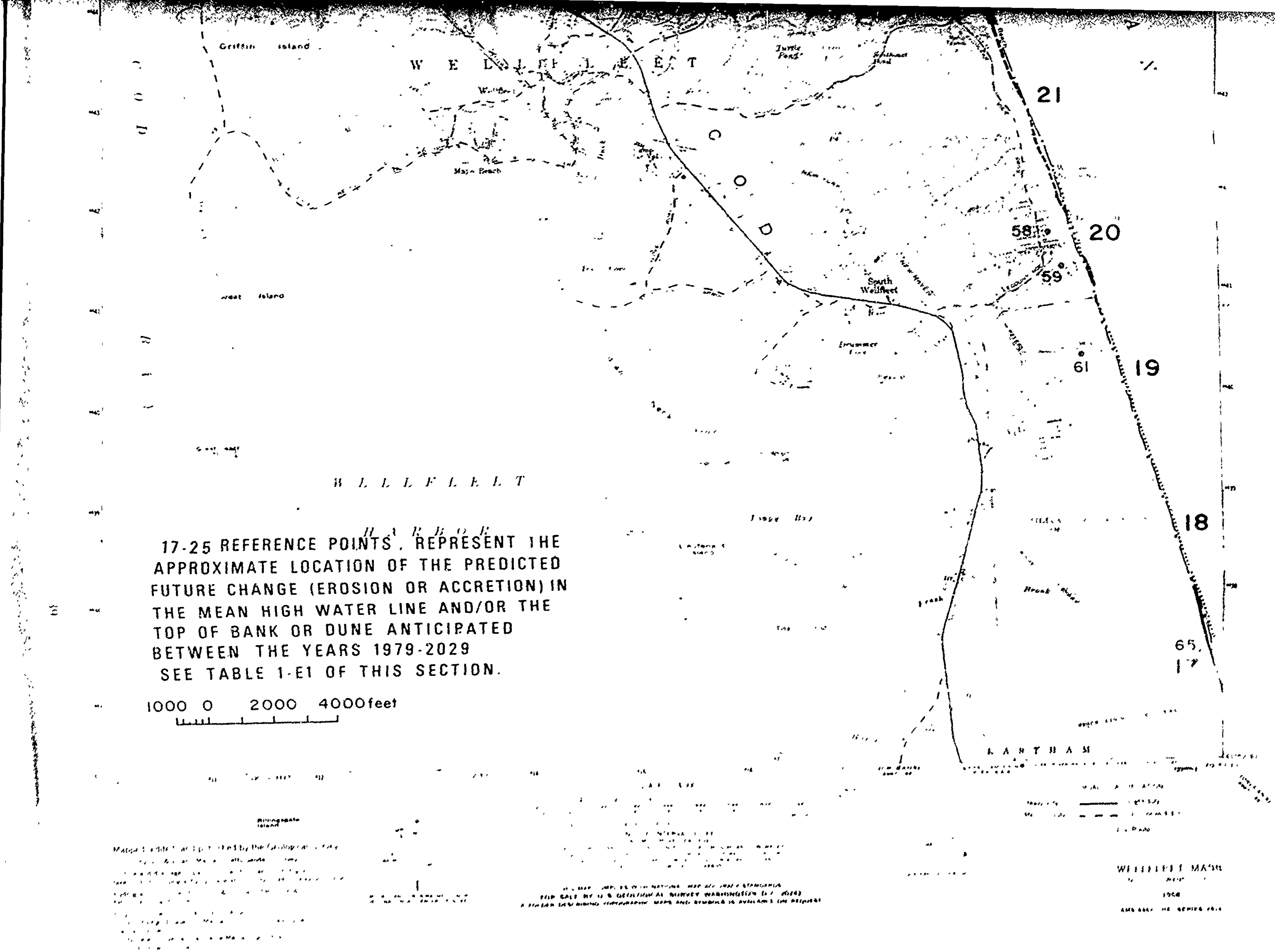


1938
1952
1971
1974
OCEAN
CAPE COD BAY
33
32
31
30
29
28
27
26
24
34
35
36
37
39
40
41
42
North Truro Air Force Station
Longnook Beach
Head of the Meadow Beach
Ballston Beach
Great Hollow Beach
Corn Hill
1000 0 2000 4000 feet
Mapped, edited, and published by the Geological Survey
SCALE 1:24 000
ROAD CLASSIFICATION
Heavy duty
Light duty
Medium duty
Unimproved dirt
U S Route
State Route
THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U S GEOLOGICAL SURVEY WASHINGTON D C 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST
NORTH TRURO, MASS
N4200—W7000/7.5
1958
AMS 6968 II SE—SERIES V814

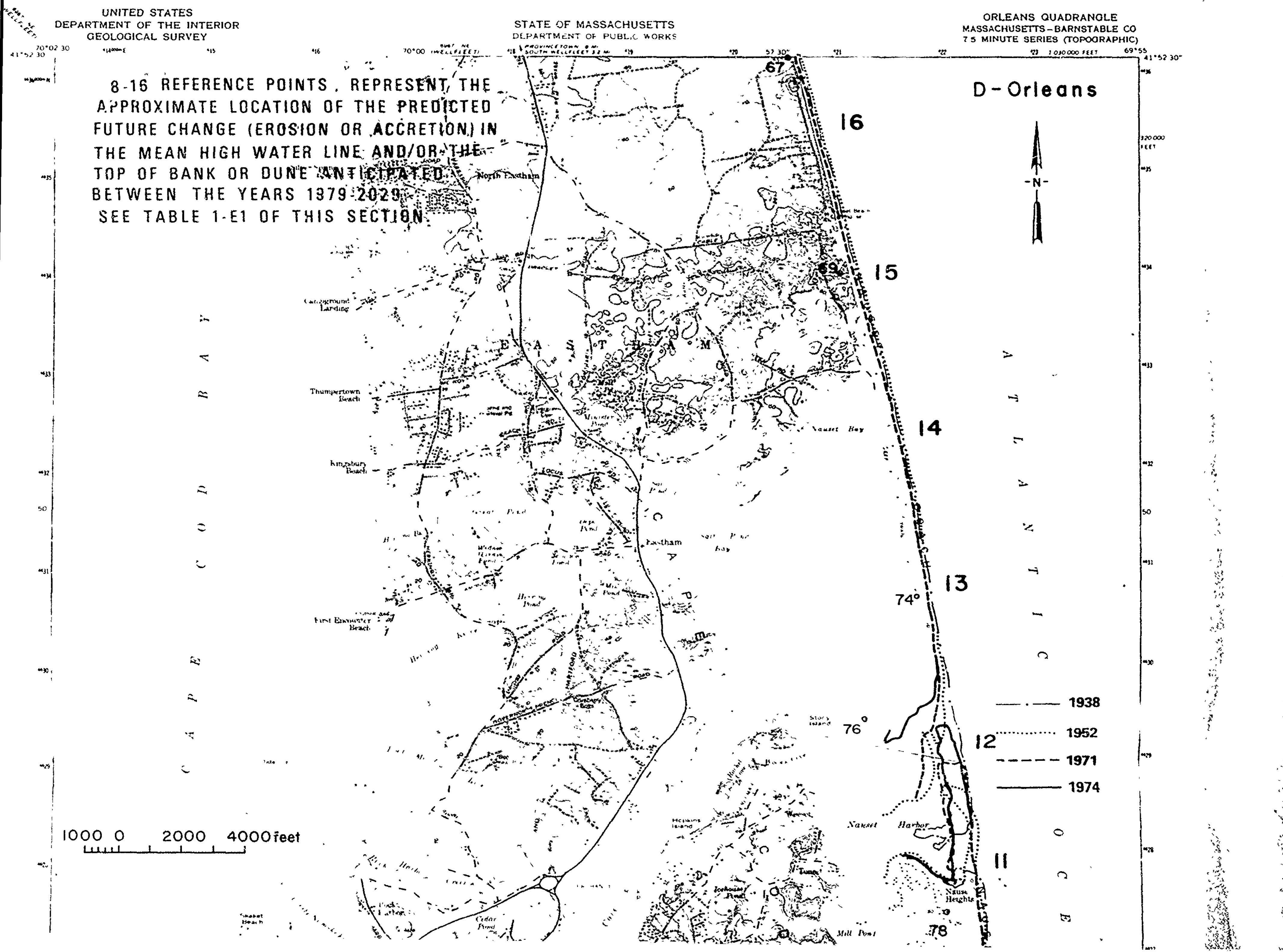

33
32
31
30
29
28
27
26
24
31
32
33
34
35
36
37
39
40
41
42
1938
1952
1971
1974
O C E A N
C A P E C O D B A Y
NORTH TRURO AIR FORCE STATION
Longnook Beach
Head of the Meadow Beach
Great Hollow Beach
Corn Hill
Harbor Bar
Ballston Beach
PILGRIM SPRING STATE PARK
1000 0 2000 4000 feet
Mapped, edited, and published by the Geological Survey
SCALE 1:24000
CONTOUR INTERVAL 10 FEET
THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U S GEOLOGICAL SURVEY WASHINGTON D C 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST
ROAD CLASSIFICATION
Heavy duty
Light duty
Medium duty
Unimproved dirt
U S Route
State Route
NORTH TRURO, MASS
N4200—W7000/7.5
1958
AMS 6968 II SE—SERIES V814

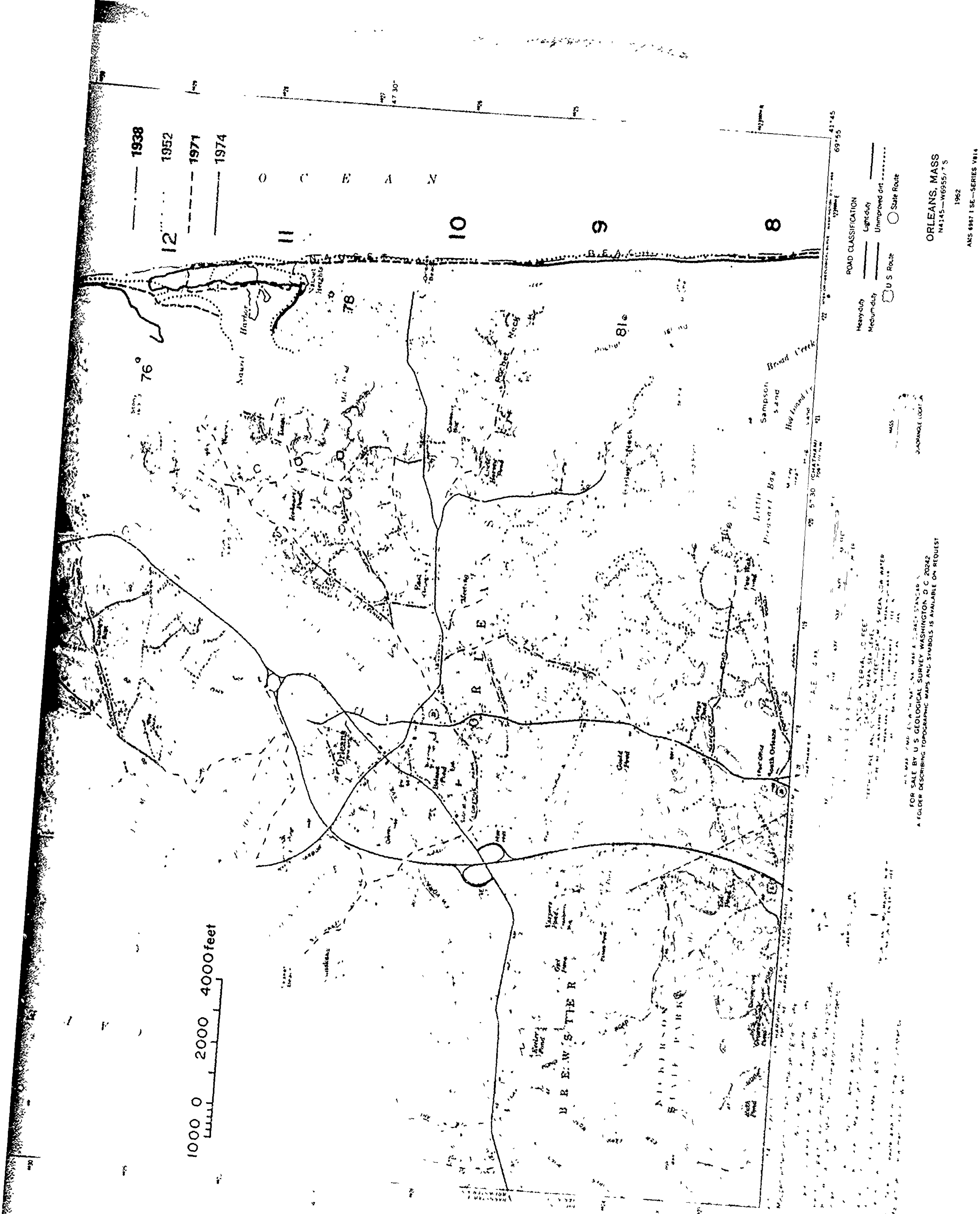


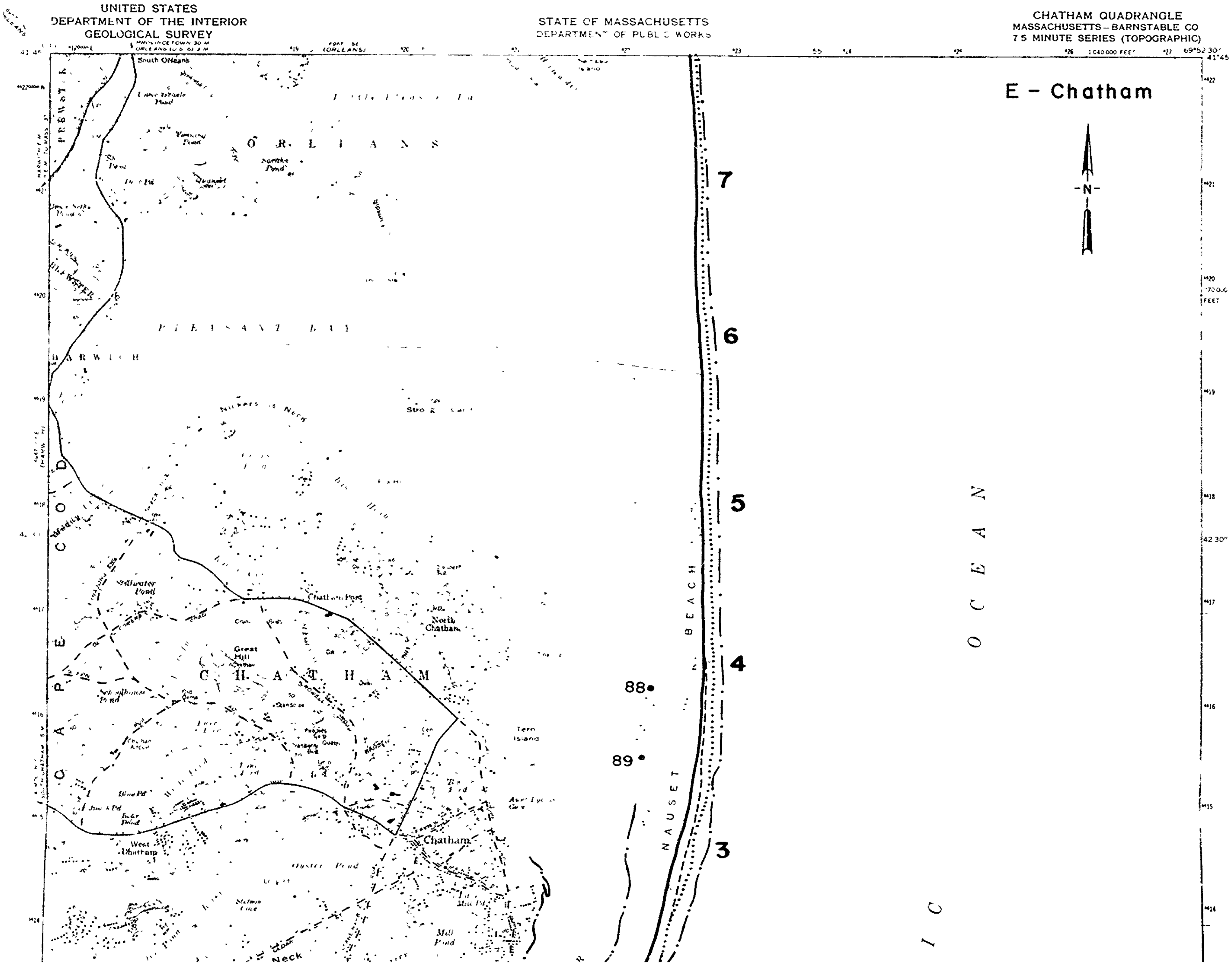
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
STATE OF MASSACHUSETTS
DEPARTMENT OF PUBLIC WORKS
WELLFLEET QUADRANGLE
MASSACHUSETTS–BARNSTABLE CO
7.5 MINUTE SERIES (TOPOGRAPHIC)
C-Wellfleet
N
1938
1952
1971
1974
ATLANTIC OCEAN
CAPE COD
TRURO
WELLFLEET
CAPE COD
43
44
25
24
23
22
21
20
49
50
51
58
59
Brush Valley
Paradise
Hollow
Griffin Island
Bound Brook Island
Gross Hill
Mayo Beach
Turtle Pond
Round Pond
South



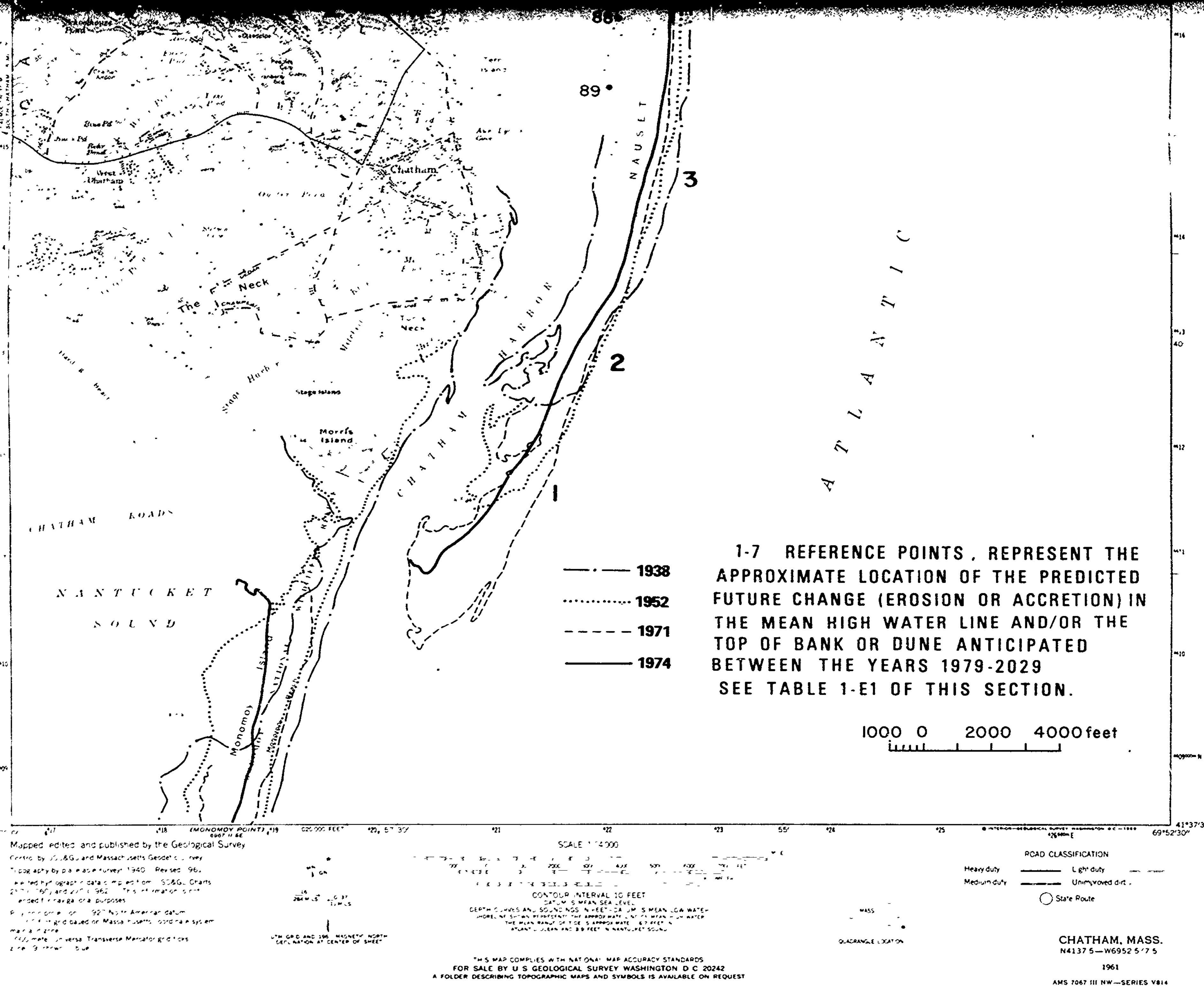
Griffin Island
W E L L F L E E T
Wellfleet
Mayo Beach
C O D
South Wellfleet
21
20
19
18
58
59
61
65
17
W E L L F L E E T
H A R B O R
17-25 REFERENCE POINTS, REPRESENT THE APPROXIMATE LOCATION OF THE PREDICTED FUTURE CHANGE (EROSION OR ACCRETION) IN THE MEAN HIGH WATER LINE AND/OR THE TOP OF BANK OR DUNE ANTICIPATED BETWEEN THE YEARS 1979-2029
SEE TABLE 1-E1 OF THIS SECTION.
1000 0 2000 4000 feet
E A S T H A M
WELLFLEET MASS.
1958


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
STATE OF MASSACHUSETTS
DEPARTMENT OF PUBLIC WORKS
ORLEANS QUADRANGLE
MASSACHUSETTS-BARNSTABLE CO
7.5 MINUTE SERIES (TOPOGRAPHIC)
D-Orleans
N
8-16 REFERENCE POINTS, REPRESENT THE APPROXIMATE LOCATION OF THE PREDICTED FUTURE CHANGE (EROSION OR ACCRETION) IN THE MEAN HIGH WATER LINE AND/OR THE TOP OF BANK OR DUNE ANTICIPATED BETWEEN THE YEARS 1979-2029.
SEE TABLE 1-E1 OF THIS SECTION.
67
69
16
15
14
13
12
11
74°
76°
78
1938
1952
1971
1974
CAPE COD BAY
ATLANTIC OCEAN
EASTHAM
CAPE
North Eastham
Eastham
Nauset Bay
Nauset Harbor
Nauset Heights
Thumpertown Beach
Kingsbury Beach
First Encounter Beach
Campground Landing
Mill Pond
Cedar Pond
1000 0 2000 4000 feet


1938
1952
1971
1974
OCEAN
12
11
10
9
8
76
78
81
Orleans
BREWSTER
1000 0 2000 4000 feet
ROAD CLASSIFICATION
Heavy-duty
Medium-duty
Light-duty
Unimproved dirt
U S Route
State Route
ORLEANS, MASS.
N4145—W6955/7.5
1962
AMS 6987 I SE—SERIES V814
FOR SALE BY U S GEOLOGICAL SURVEY WASHINGTON D C 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST



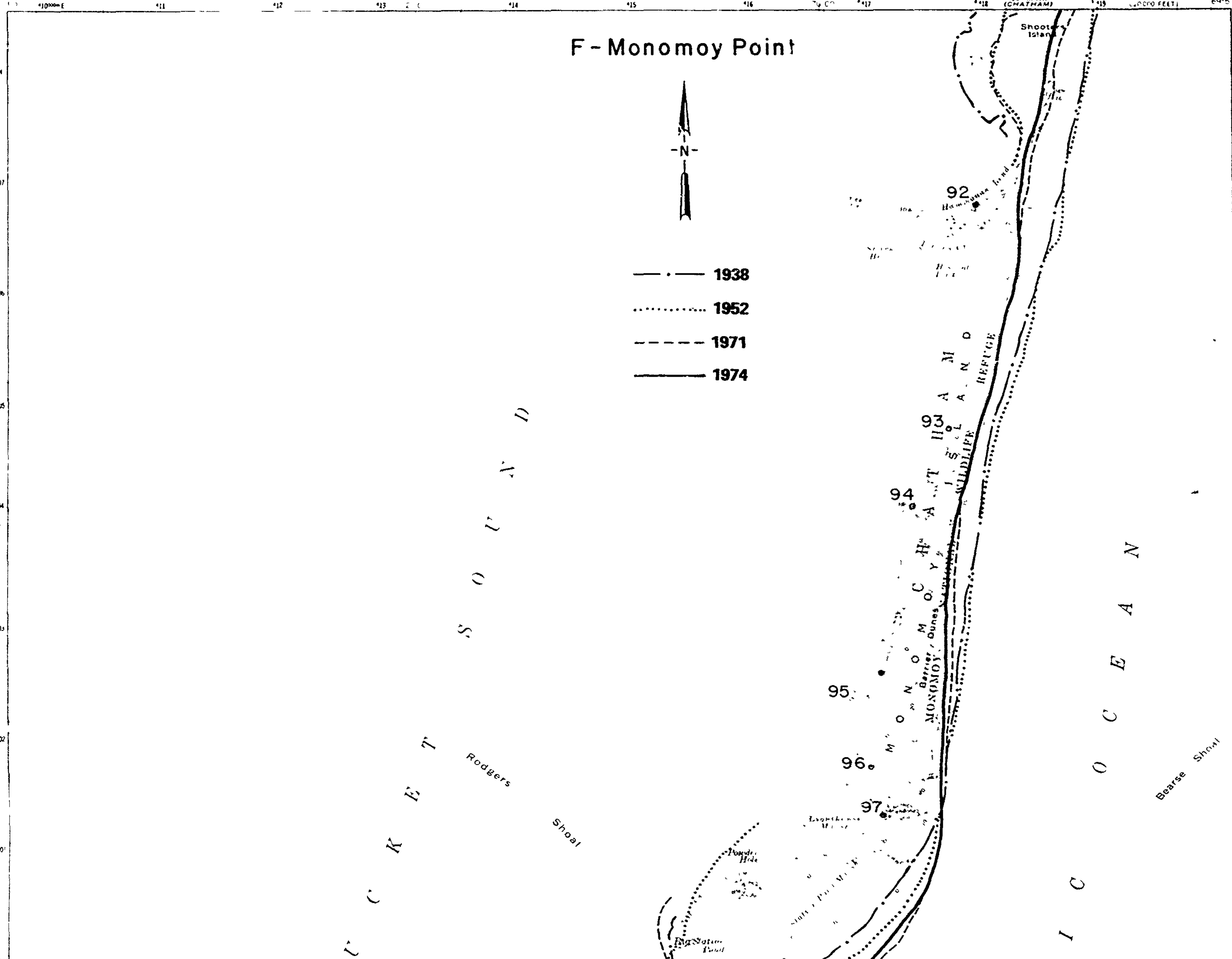
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
STATE OF MASSACHUSETTS
DEPARTMENT OF PUBLIC WORKS
CHATHAM QUADRANGLE
MASSACHUSETTS – BARNSTABLE CO
7.5 MINUTE SERIES (TOPOGRAPHIC)
E – Chatham
N
7
6
5
4
3
88
89
NAUSET
BEACH
OCEAN
ORLEANS
PLEASANT BAY
HARWICH
CHATHAM
CAPE COD
Tern Island
North Chatham
Chatham
West Chatham
Great Hill
Oyster Pond
Mill Pond
South Orleans
Nickerson Neck

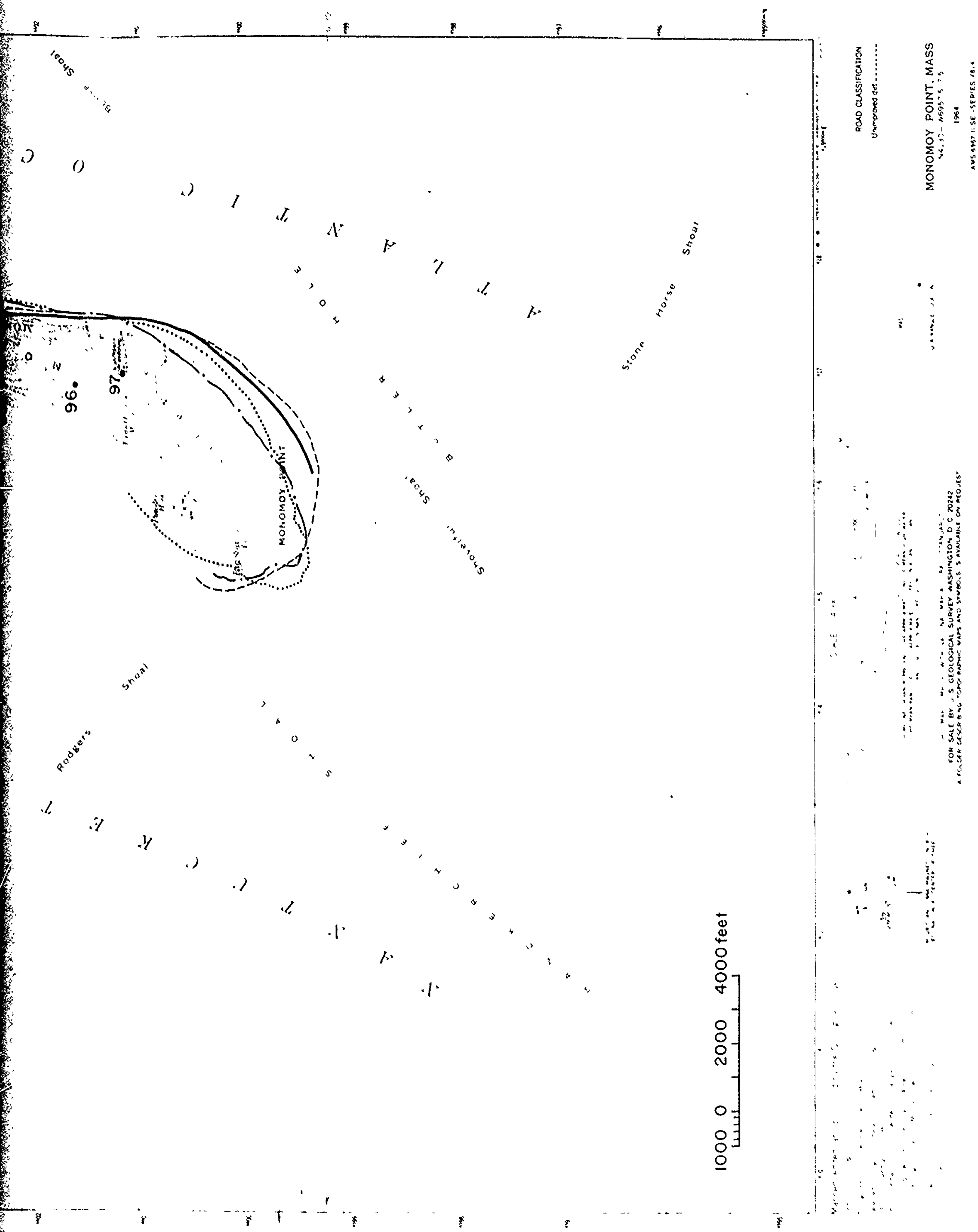


1-7 REFERENCE POINTS, REPRESENT THE APPROXIMATE LOCATION OF THE PREDICTED FUTURE CHANGE (EROSION OR ACCRETION) IN THE MEAN HIGH WATER LINE AND/OR THE TOP OF BANK OR DUNE ANTICIPATED BETWEEN THE YEARS 1979-2029
SEE TABLE 1-E1 OF THIS SECTION.
1938
1952
1971
1974
1
2
3
89
ATLANTIC
NAUSET
CHATHAM HARBOR
Chatham
The Neck
Morris Island
Stage Island
NANTUCKET SOUND
CHATHAM ROADS
Monomoy
(MONOMOY POINT)
1000 0 2000 4000 feet
Mapped, edited, and published by the Geological Survey
SCALE 1:24 000
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
ROAD CLASSIFICATION
Heavy duty
Light duty
Medium duty
Unimproved dirt
State Route
QUADRANGLE LOCATION
THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U S GEOLOGICAL SURVEY WASHINGTON D C 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST
CHATHAM, MASS.
N4137.5—W6952.5/7.5
1961
AMS 7067 III NW—SERIES V814
41°37'30"
69°52'30"

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

MONOMOY POINT QUADRANGLE
MASSACHUSETTS–BARNSTABLE CO
7.5 MINUTE SERIES (TOPOGRAPHIC)




MONOMOY POINT, MASS
1964
ROAD CLASSIFICATION
Unimproved dirt
FOR SALE BY U S GEOLOGICAL SURVEY WASHINGTON D C 20242
A T L A N T I C
O C E A N
Stone Horse Shoal
Shovelful Shoal
Rodgers Shoal
MONOMOY POINT
97
96
1000 0 2000 4000 feet

SECTION F

LAND USE ON OUTER CAPE COD

LAND USE ON OUTER CAPE COD

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PRESENT LAND USE

Introduction

This section provides a brief description of land-use patterns, including some background economic and population data to explain those patterns, on the outer arm of Cape Cod from Provincetown to Chatham. Although much of the report is based on land use in 1971, additional information has been added to indicate general changes between 1971 and 1976. Major shifts in land use between 1951 and 1971 are discussed to give an idea of the trends in development for each town.

Cape Cod is a narrow, hook-shaped peninsula extending eastward from southern Massachusetts. It is a part of the northeastern coast of the United States, near the northern end of the megalopolis which extends from Washington, D.C., to southern Maine. The megalopolis is not uniformly urban but varies from densely populated, heavily industrialized centers to lightly populated rural areas. [Although population has increased since 1971 even in rural areas, the greatest growth has been in already populous areas of the megalopolis. Urban areas have expanded into agricultural and forest lands.]

This urban sprawl has destroyed much of the green space people sought in moving out of central sites. An increasing number of people have searched for a more rural setting for vacations or second homes, or for year-round retirement homes. In Massachusetts, Cape Cod (Barnstable County) has been the location of much of this recent development.

At the same time, Cape Cod's sandy, unprotected coastline has been subject to problems of shoreline erosion and sedimentation. This erosion threatens areas that have already been developed for residential and recreational use, and studies have shown that human activity often accelerates erosion and sedimentation. Thus, there is a particular need to understand present use of land on Cape Cod and the continuing development forces that may further threaten the environment.

Land -Use Regulatory Mechanisms

Regulation of land activities has only recently begun to consider special impacts on the coast. There are two major regulators, the local and Federal governments. Each has different interests and authority, as illustrated by two of the more rec~nt coastline-related programs they administer in Massachusetts.

Wetlands Protection: M.G.L.A. c.131 s.40 - The cities and towns of Massachusetts administer the Wetlands Protection Act under a grant of State authority - a situation duplicated in all other local land regualtory activity. The statute requires that a town protect its inland and coastal wetland areas by closely regulating any alteration of them for development. The town cannot absolutely prohibit any use of privately owned wetlands; the state courts have, however, upheld severe restrictions or limited permissible uses. In addition, although local authority to regulate uses in wetlands under this statute is strong, it does not authroize local governments to impose conditions on contiguous uplands. The authority to permanently restrict uses in contiguous coastal uplands rests with the state Department of Environmental Management under Chapter 131, section 105. Thus, in this instance, municipal authority to regulate land use to prevent erosion and sedimentation is focused but limited.

Water Quality Planning; PL 92-500 s.208; and Permits to dredge and fill: 33 U.S.C.A. ss.401, 403, 404 - These two programs, which are administered by the Federal government, represent opposite approaches to the question of land regulation to prevent erosion and sedimentation. The water quality planning program ("208") provides funds to states and regions to develop water quality management programs and then qualifies State and local governments for grants to construct wastewater treatment facilities. Although no State or town is required to participate, the mandatory clean-water standards that must be met at both the state and local level have effectively produced large-scale participation. Section 208 and the standards both directly address the problems of sedimentation and erosion. Section 208 requires, as part of a region's nonstructural program, both land use regulatory mechanisms to reduce potential pollution of rivers, harbors, and the ocean and strict regulation of construction practices to limit sediment runoff at building sites. Both the planning and standards programs represent one end of the spectrum of federal invovlement in land-use regulation - an approach based on minimum mandatory standards and financial incentives. At the other end, far beyond that of local regulatory authority, is the U.S. Army Corps of Engineers' authority to regulate development of the country's navigable waters, an area which has been defined to include virtually all water in the United States. Here, the federal government, itself, retains complete power to regulate the alteration of all tide-lands and wetlands, superceding even the state's authority in these issues. This is an area in which the federal government has essentially preempted state and local activity in the name of the national interest. In recent years, the Corps has been increasingly concerned about land as well as water uses in these areas, and permit applications for dredge and fill operations have been closely scrutinized for coastal impacts, particularly on water quality, erosion, and sedimentation.

As may be seen from the above examples, local and federal agencies employ a range of powers to promote environmentally sound land-use practices in coastal areas. In general, local governments rely on police power techniques to restrict damaging uses, although there are a few outright prohibitions.

The record of local government in Massachusetts in using positive as well as negative incentives to preserve coastal areas is limited to the acquisition of beaches and the construction of town docks and launching ramps, despite an array of available state programs. On the other hand, the federal government has used incentive programs liberally to promote coastal planning and rgulation at the state and local levels, and it has also applied its regulatory power broadly to prevent excessive erosion and sedimentation. A more complete list of existing local and federal regulatory authority follows, as well as description of some applicable state programs.

Regulatory Programs: Federal

<u>Permits for Dredging and Filling in Navigable Waters: 33 U.S.C.A. ss.401, 403, 404</u>

This program is discussed briefly above; in general, it effectively regulates all shorefront construction including work along harbors, waterways, wetlands, rivers, and tributary streams. New interpretations of the extent of jurisdict'on here have brought environmental and social concerns into play in recent permit decisions.

<u>Atomic Energy Commission Licensing of Nuclear Power Plants: 42 U.S.C.A. ss. 2131 et. seq.</u>

Coastal areas are the preferred locations for nuclear power plants because of the immediate availability of water for the plants' cooling systems. Construction of any large power plant in fragile coastal areas can have serious repercussions in terms of erosion and sedimentation, particularly as these processes are affected by construction and outfalls from the cooling system.

<u>Offshore Oil and Mineral Leases: Outer Continental Shelf Lands Act of 1953</u>

The issuance of offshore exploration leases in itself does not affect land use, but the discovery of oil, gas, or minerals offshore can have a major impact on the coast if development of those resources requires onshore facilities. Here again, construction will have an important impact on coastal erosion and sedimentation, with the added factor of increased pressure on harbor and port facilities.

<u>Marine Sanctuaries: 16 U.S.C.A. ss.1431 et. seq.</u>

Under this program, the Secretary of Commerce may designate ocean or tidal sanctuaries in order to preserve their environment or natural resource characteristics. Once designated, all public and private development in the area must be consistent with the purposes of the sanctuary. This regulatory authority, which has not been exercised on the New England coast, could have important effects on land and water activities within the sanctuary. However, it is unclear how extensive this regulatory authority is, in regard to purely land-based development if it cannot be shown to have a direct impact on the sanctuary's waters.

Flood Plain Insurance Act: 42 U.S.C.A. ss.4001 et. seq.

The Flood Plain Insurance Act was established to provide federal support to insure existing buildings in the flood plain and to discourage further construction in the flood plain area. A provisional level of 10 feet above mean high tide has been set for most of the outer Cape, but none of these towns has yet been mapped in detail to define the official flood zone. Truro has officially rejected the 10-foot provisional level, but no acceptable definition of the flood plain zone has been settled. The importance of this act is that it will restrict future building near the coast in low-lying areas and so will affect land use in all of the outer Cape towns.

Cape Cod National Seashore: Administered as part of the National Parks System

The National Seashore encompasses both public and private lands with the purpose of preserving the natural environment and providing recreational and educational opportunities. The regulatory power of the Seashore Administration over land within its boundaries is extensive and has increased as the federal government has acquired more of the land from private interests. In terms of erosion and sedimentation reduction, the Seashore controls much of the most vulnerable shoreline on Cape Cod (see Figure 1-F1 and Table 1-F1). Note: The figures, tables, and plates for this section are at the end of the section because they are referred to throughout the discussion.

Regulatory Programs: State

Licensing of Construction Work Along Waterways: M.G.L.A. c.91 ss.12-27

The power to regulate construction in the territorial waters of Massachusetts rests with the State Department of Environmental Quality Engineering and includes the construction of wharves, piers, dams, sea walls, roads, bridges, and pipelines. In addition, the Department can prohibit the destruction or removal of vegetation and the removal of earth on land bordering on tidelands; these powers are important in the control of erosion and sedimentation in coastal areas.

Ocean Sanctuaries: M.G.L.A. c.132A ss.13-16

This statute establishes four ocean sanctuaries, one being the area offshore of the eastern edge of Cape Cod. The provisions are aimed specifically at activities that would be located on land under the ocean within the area, such as mineral removal and cable platform and pipeline construction. Although none of these provisions has been implemented, they could be an important tool in further protecting wetlands and beach areas.

Energy Facilities Siting Council: M.G.L.A. c.164, ss.69G et. seq.

This Council is responsible for issuing permits for all energy-related facilities in Massachusetts. Its powers are extensive, combining the separate permit powers of other functional agencies and the power to override local decisions. Production, transmission, and generation facilities are all included in the Council's jurisdiction, and its powers include the authority to issue regulations designed to minimize environmental damage.

Permanent Restrictions by Deed of Uses in Wetlands: M.G.L.A. c.130 s. 105; c. 131 s. 40A

The Division of Environmental Management is empowered to impose permanent restrictions on the use of inland and coastal wetlands, lowlands, and contiguous uplands. Conservation Commissions can bar any attempted development on restricted land, once such restrictions have been recorded.

Regulatory Programs: Local

Wetlands Protection Act: M.G.L.A. c.131 ss.40, 40A, 105

As described above, this statute confers on local Conservation Commissions the power to regulate development in wetlands and lowlands subject to flooding for the purpose of preventing damage or elimination of wetland areas. The authority vested in this statute is substantial but narrowly focused; its impact would be felt most strongly at the interface of land and water along the coast and its streams.

Zoning: M.G.L.A. c.40A

Zoning ordinances may be the most powerful land regulatory tools available to local government for the prevention of erosion and sedimentation. Regulations governing lot size, setback, size of structure, and densities can all promote erosion control by restricting development to less vulnerable areas and by limiting development in erosion-prone areas. Of particular importance is the presumption of validity given these ordinances by the courts and the expanding view of police power jurisdiction on which zoning authority is based. Recent variations in traditional zoning practice include large-lot zoning, cluster and planned unit developments, impact zoning, and moratorium on growth, all of which may be useful in shoreline erosion and sedimentation control.

Subdivision Control: M.G.L.A. c.41 ss.81K-81GG

The power to regulate new residential construction is of considerable importance to Cape Cod, which has experienced substantial vacation and retirement home development. The requirements placed upon new subdivisions may include many provisions, in both the construction and occupancy stages, which limit erosion and sedimentation. In particular, the use of plans that minimize cut-and-fill operations, encourage retention of vegetation, incorporate storm drainage, and limit paved areas is effective in limiting erosion. Here again, subdivision control bylaws are presumed valid unless clearly proved arbitrary or capricious.

Public Health Regulation: M.G.L.A. c.111 s.31

A local board of health administers the state sanitary code, approves landfill sites, and regulates trades that may create public health nuisances. In cases where erosion or sedimentation may present a public health hazard, the board's power to act is extensive and may extend to an outright prohibition on those activities that cannot effectively moderate their impacts.

Earth Removal: M.G.L.A. c.40 s.21; c.40A s.2

The removal of sand, loam, and gravel was originally regulated under the zoning authority of a town; more recently, separate legislation has been adopted to deal comprehensively with this activity. Most towns continue to permit earth removal in certain specified areas, but most have regulations to eliminate the undesirable impacts of erosion and sedimentation by requiring drainage control, buffer zones, screening, measures to reduce dust, and the grading and reseeding of excavation areas when the work is done.

Description of County and Townships

Barnstable County

General

Barnstable County (Cape Cod) is a peninsula that is cut off from the rest of Massachusetts by the Cape Cod Canal. The bridges that cross the Canal at Bourne and at Sagamore are about 55 miles from Boston, and the Cape extends another 57 miles to Provincetown. Cape Cod's heavy dependence on tourism has shaped much of the present land use and will continue to influence development in the future. Because people come to Cape Cod partly to enjoy a change from urban areas and to participate in outdoor recreation activities, an attractive, natural environment is a vital part of the area's appeal.

Population

The population of Barnstable County has grown rapidly in the past 25 years, in terms of both year-round and seasonal residents. In 1950, year-round population was 48,805; in 1976, it was estimated to be 128,849, an increase of 168 percent. Seasonal population was estimated to be 389,724 in 1976, about three times the number of year-round residents (Table 1-F2). The seasonal population includes many families that come to a second home on the Cape to spend all or part of the summer. It also includes many

visitors who stay in public accommodations overnight, a few days, or several weeks. In recent years, many people have retired to Cape Cod, some to their former summer homes, and the age structure of the Cape has shifted accordingly to a higher proportion of people over sixty. The general decline in birthrate has resulted in a smaller proportion of preschool and school age children. Some of the older people who view Cape Cod as their year-round home go away to Florida or other places with milder climates for several months during the winter.

Tourism

Cape Cod depends heavily on the tourist industry for employment and payrolls to support its economy. Cournoyer and Kindall (1975) attribute 85 percent of summer payrolls on Cape Cod to the direct impact of travelers in the area, almost 15 percent even in winter. Employment patterns for Barnstable County reflect the importance of tourism: average employment is highest in wholesale and retail trade, second highest in services (Table 1-F3). Construction ranks third as an employer and is closely tied to fluctuations in the market for second homes.

Tourists come to Cape Cod for a variety of reasons - to view historic sites and natural scenery, to participate in swimming, boating, and hiking, and to attend special events such as town fairs or fishing tournaments. The summer months are the peak season, when all the special attractions, such as museums, are open and all the outdoor activities such as water sports can be enjoyed. In the fall and spring, even in the winter, the Cape still holds appeal as a contrast to urban areas; the scenery and towns can all be appreciated while driving, hiking, or bicycling during this "off season."

Tourists come to the Cape from all over the United States, from Canada and from other countries. One study by the Cape Cod National Seashore showed that 30 percent of all visitors were from Massachusetts, 45 percent from the nearby states of Connecticut, New York, and New Jersey. Tourists may stay on the Cape for less than a day or for the entire summer season. A wide variety of specific activities appeals to a broad range of interests among tourists: fishing, swimming, boating, picnicking, hiking, bicycling, touring historic sites and houses, attending art shows and concerts, viewing scenic areas from a car or on foot, shopping, eating seafood, camping, and watching birds and other wildlife.

Land Use

Land use reflects the economic and population characteristics of Cape Cod. In 1971, about 80 percent of the land area was covered by forest, agricultural, or open lands or wetlands (Table 1-F4). Residential housing accounted for another 14 percent of the area, outdoor recreation 2 percent, and only about 1 percent each for industrial-commercial, open public, and mining-waste disposal. Even though this breakdown is heavily dominated by open or natural areas, the land use in 1951 was even less developed (Table 1-F5). Only 5 percent of land area was residential,

and 93 percent was forest, agricultural, or wetlands. Plates F-1 through F-3 illustrate the distribution of these various land uses in 1971.

Land-Use Changes and Environment

The change in residential area during the 20-year period between 1951 and 1971 reflects the increase in population, both seasonal and year-round, living in Barnstable County (Tables 1-F4 and 1-F5 and Plates F-1 through F-3). Open and agricultural land has declined primarily because of housing developments, and also because abandoned fields and pastures have grown up into young forests of scrub oak and pitch pine.

In the past 25 years, many of the towns on the Cape have become more aware of the importance of preserving the environment, but many residents are also very concerned that development continue in order to provide stimulus for the local economies. Conflicts within towns have sometimes resulted in town purchase of areas as natural areas or watersheds that had been considered as sites for housing developments. In other cases, development has proceeded rapidly to replace former natural areas. In part, the strength of these two contrary forces seems to depend on the existing density of housing and proportion of natural areas left in towns. The towns which are already heavily developed into residential and commercial areas seem more concerned than lightly developed towns to preserve their remaining natural areas, except where substantial areas have already been set aside by the Cape Cod National Seashore. In all of the outer Cape, the major force acting to preserve natural areas has been acquisition of land by the Cape Cod National Seashore. This has provided all the towns of the outer Cape with a federal designation of an area to be preserved for the use of all, with no further commercial or residential development. The boundaries include 16 percent of the land area in Barnstable County, 60 percent of the outer Cape area. The National Seashore also provides outdoor recreation areas to be used by transitory tourists and more permanent residents.

Transportation

Transportation is dominated by the highway and road system; the major highways are Route 6, which goes the length of the county, and Route 28, along the southern edge of the county. The only remaining active railroad lines are one from Bourne to Falmouth, which has freight service once a week, and another from Sandwich to Dennis and Hyannis, which has freight service twice a week. Even these railroad tracks are in poor condition and restrict trains to very slow speeds; other railroad lines on the Cape are inactive. Several airports are located on the Cape, the largest are Otis Air Force Base Airport, Hyannis Airport, and Provincetown Airport.

Provincetown

General

Provincetown is at the tip of Cape Cod, 112 miles from Boston by highway. The densely populated town center of Provincetown is along the inner bay and is cradled inside a large relatively undeveloped area controlled by

the National Seashore. Provincetown is interesting for many reasons: the Pilgrims first landed here, it is a famous art colony, and miles of natural low sand areas and high dunes surround the town area. Its unusual geographic position has led to a dependence on the sea for its entire history, including a period of whaling. Today the town, itself, is heavily dependent on tourists. Some people are attracted by the seashore, which includes such well-known areas as Race Point Beach, Herring Cove Beach and the high dunes. Tourists are also drawn by the artists' colony and the fishing fleet which contribute to the interest of the town, itself.

Population

Although Provincetown's year-round population declined by 23 percent between 1950 and 1970, the growth between 1970 and 1976 more than compensated for the decline. However, the number of dwelling units increased by only 5 percent between 1970 and 1975. By 1976, year-round population was about 24 percent of the seasonal 16,995 people (Table 1-F2).

Tourism

As is typical of the entire Cape, the local economy is dominated by tourism, with a year-round average of 74 percent of total employment in wholesale and retail trade and services. Provincetown is also the major fishing port on this part of the Cape, accounting for 7 percent of employment as a year-round average (Table 1-F3). The seasonal nature of the town's tourism-dependent economy is indicated by the contrast of a January low employment only 30 percent of employment in August. The attractions of Provincetown for the tourist have already been reviewed. The town's character is in strong contrast to the surrounding natural areas of the National Seashore and makes a particularly interesting area for visitors to explore.

Vistors come to Provincetown not only by car and bus along the highway but also by airplanes landing at the Provincetown Airport within the boundary of the National Seashore.

Land Use

Provincetown in 1970 used only 4 percent of its land for residential purposes, an additional 3 percent for other urban activities - commercial, industrial, and transportation. This is the smallest proportion of land for residential use of any of the Cape towns. In fact, however, most of the residential areas are very high density. The preponderance of open lands, forest, and wetlands is within the National Seashore and unavailable for development. The only commercial area outside the densely populated town is the Provincetown Airport, which is among the hills, dunes, and plains of the National Seashore. Housing built in the past few years continued to be high density, mostly cottages but including some condominiums (Tables 1-F4 and 1-F5). The figures show 1971 distribution of forest and open land, wetlands and beaches, residential areas and commercial areas.

Since 1950, there has been a slight increase in forested area, probably helping to stabilize the large dune areas. The slight overall increase in commercial area can be attributed to the development of areas near the highway and along the major roads in town for serving tourists.

Truro

General

Just below Provincetown, Truro is 102 miles from Boston. The small population is scattered lightly about the town, and many undeveloped areas remain inside and outside the National Seashore. Truro includes wooded areas as well as beaches and wetlands. Some of the interesting features of the town are the Pamet River area, Head of the Meadow Beach, High Head and Pilgrim Heights, and the marshes and tidal flats along Cape Cod Bay.

Population

Truro's population is next to smallest on all of Cape Cod, but the number of year-round residents has increased rapidly since 1950 - almost 93 percent by 1976 (Table 1-F2). Truro's year-round population is only about 11 percent of the seasonal high of 11,834, the lowest proportion on the outer edge of the Cape.

Tourism

Truro's major appeal to tourists is its generally rural, undeveloped atmosphere. Striking contrasts in types of land and vegetation exist in the National Seashore. Some specific areas of interest were mentioned above. Also, a golf course in the Highlands area provides a recreation resource. Most of the recent housing developments have been for seasonal use.

Despite the rapid growth in population, Truro's economic base remains small. Employment, fluctuating between 386 in August and 52 in January, averages only 200 year-round. Most of these people work in service industries (Table 1-F3). For major shopping and many other activities, residents and visitors go to the adjacent towns of Provincetown and Wellfleet.

Land Use

Residential land by 1970 was 8 percent of the total area, up from only 1 percent in 1951 (Tables 1-F4 and 1-F5 and Plats F-1 through F-3). Most of this area had been open and agricultural land in 1951. Over that period, new commercial areas along the highways added 90 acres to the 6 acres of commercial land in 1951. Truro contains more acres of the National Seashore than any other town except Wellfleet (Table 1-F1); this area will continue to be natural and recreational. One unusual feature within the National Seashore is the North Truro Air Station. Other parts of the town are expected to continue the expansion of developed areas which marked the past 25 years. Between 1970 and 1975, the number of dwelling units rose by 12 percent (Table 1-F6).

Wellfleet

General

Wellfleet, midway on the outer arm of the Cape, between Truro and Eastham, is about 94 miles from Boston. Bordering both the Cape Cod Bay and the Atlantic Ocean, Wellfleet contains a large harbor, extensive salt marshes and many freshwater ponds. Major points of interest include Griffin Island and Great Island, the Atwood-Higgins house and other historical sites, Marconi and Bay Side beaches, and the White Cedar Swamp. Wellfleet draws commerce from the adjacent towns to its pleasant downtown area.

Population

Wellfleet's year-round population has grown by 78 percent between 1951 and 1976 (Table 1-F2). Despite this rapid growth, the year-round population remains only about 15 percent of the seasonal high. As in other parts of the Cape, much of the recent population growth has been retired people seeking a more rural area.

Tourism

Tourism is a vital part of Wellfleet's economic base. Because Wellfleet is a local center of commerce for residents and tourists, wholesale and retail trade account for almost two-thirds of average employment (Table 1-F3). The winter low in employment is about 30 percent of the summer high. In addition to the points of interest listed above, Wellfleet has a marina in the harbor which attracts boats for all sorts of water sports.

Land Use

Land use in Wellfleet includes 12,300 acres within the National Seashore (Table 1-F5). Overall, the township retains 87 percent of its land area as open, forest, or wetlands (Tables 1-F4 and 1-F5 and Plates F-1 through F-3). Enough open land remains within the town's control that the present rate of residential development is likely to continue. Between 1970 and 1976, the number of housing units increased by 20 percent (Table 1-F6).

Wellfleet's commercial area is concentrated in a pleasant area away from the main highway, but recent commercial growth has included more business near the highway to serve vacationers. This shift in commercial development should help to preserve the attractive character of the town's older section.

Eastham

General

Eastham, just south of Wellfleet and 88 miles from Boston, is the second smallest town on the Cape. Eastham boasts two of the National Seashore's most popular beaches: Coast Guard Beach and Nauset Light Beach, both on

the ocean. Additional town beaches are located on the Bay side. Extensive salt marshes are found in Salt Pond Bay near the ocean and surrounding Herring River and Boat Meadow River on Cape Cod Bay. Many other parts of town including areas controlled by the National Seashore are wooded. The homogeneous residential community gives the town a character of its own which adds to the attractions of the National Seashore area.

Population

Eastham's year-round population has more than tripled between 1950 and 1976 (Table 1-F2). The 1976 seasonal population of 16,774 was over five times greater than the year-round population.

Tourism

Eastham's heavy dependence on tourism is partly shown by the large seasonal fluctuation in population. Employment also fluctuates, hitting a low in February of 40 percent of summer levels. Wholesale and retail trade is the largest employment category (42 percent). The construction industry employs almost as many people, on an average, as services, about 22 percent each (Table 1-F3).

Land Use

As would be expected from the rapid population growth, Eastham has had a large increase in urban land use since 1951 (Tables 1-F4 and 1-F5 and Plates F-1 through F-3). Urban land, all but a few acres residential rather than commercial, grew from less than 4 percent of the town's area in 1951 to 17 percent in 1971. The major loss of agricultural and open land during that same period was due to residential area growth and also to growing up of some open land and scrub forests. Dwelling units rose by 24 percent between 1970 and 1975 (Table 1-F6). Forest has actually increased from 48 percent to 50 percent. More residential development in forested areas is expected, as most of the open land available outside the National Seashore has been developed. As with other towns on this part of the Cape, the large area within the National Seashore boundary restricts the amount of land in Eastham which can be developed (Table 1-F1).

The town expects steady growth in the future and hopes to preserve its residential character. Business will continue to be kept mainly along the highway strip.

Orleans

General

Just north of Chatham, Orleans borders on the Atlantic Ocean, Cape Cod Bay, and Pleasant Bay. It is 86 miles from Boston. Its location provides almost all possible water activities offered by any other Cape Cod

community. The environment and character of the town have contributed to its steady appeal to tourists and retired people. A stable zoning system has enabled town officials to keep growth to a reasonable pace, although growth has fluctuated in response to general economic changes.

Population

Orleans has a larger ratio (38 percent) of year-round to seasonal population than any of the other towns on the outer part of Cape Cod (Table 1=F2). Population has increased 151 percent between 1951 and 1976 to 4,424. Seasonal population for 1976 has been estimated to be 11,754. Dwelling units increased almost 31 percent between 1970 and 1975 (Table 1-F6). Growth in the past decade has been steady, and the town plans to continue zoning, pollution, and population density restrictions to control future growth.

Tourism

Orleans serves as a local center of commerce, although the tourist industry is also clearly important (Table 1-F3). About 58 percent of emp'cyment, on an average, is wholesale and retail trade. The 9 percent of total employment in transportation, communication, and utilities is a higher proportion than any other town on the outer Cape. Seasonal employment fluctuates less than for most Cape towns: winter employment is nearly two-thirds of the summer peak. Besides the many water-related activities offered by Orleans, people are attracted by other recreation facilities, such as tennis courts, and by the summer theater and park shell.

Land Use

Urban land use has risen from 6 percent in 1951 to 15 percent in 1971 (Tables 1-F4 and 1-F5 and Plates F-1 through F-3). Most of the increase has been in medium- and light-density residential areas, but commercial and industrial areas have also grown. Forests and wetlands covered about the same 75 percent of the total in 1971 as in 1951. Most of the new residential and commercial areas came from open fields and pastures.

The National Seashore covers less than 30 percent of Orleans, in contrast to the dominant position of the Seashore in towns to the north (Table 1-F1). Although wetlands are protected from development, the remaining non-seashore open and forest lands of Orleans are subject to further residential development. However, such development will be carried out within the town's very stable zoning system and will reflect the town officials' concern to maintain the town's character.

Chatham

General

Chatham, on the ocean side of the southern tip of the elbow of Cape Cod, is the largest township on the outer Cape. The town has both an attractive, densely populated downtown area with many historic homes and a

large endowment of recreational facilities. Chatham has more saltwater beaches (492 acres) than any other town on the Cape. In fact, three sides of the town are surrounded by water. Other attractions include the National Wildlife Refuge at Monomoy Point and a variety of developed outdoor recreation areas, including two golf courses and a marina. Although most people come to Chatham along the highway system, Chatham also has an airport.

Population

Chatham's population, both year-round and seasonal, is larger than that of any of the other five towns on the outer Cape. Chatham's year-round population grew almost 150 percent between 1951 and 1976 to 6,118 people (Table 1-F2). Between 1950 and 1970, it grew 86 percent, so there has been an acceleration in the 1970s. Seasonal population was 19,874 in 1976, 22 percent of the total for the six towns on the outer Cape. Year-round population is over 30 percent of seasonal, a higher proportion than any town except Orleans. Like Orleans, Chatham has become more popular as a year-round residence for retired people in recent years.

Tourism

Chatham's large year-round population contributes to a steady economic base, but tourism is a central element in the economy. The three leading industries reflect the importance of commerce and tourism: 49 percent of employment is in wholesale and retail trade, 28 percent in services and 11 percent in construction (Table 1-F3). The Chatham fishing industry is not insignificant with 3 percent of employment; its role as a year-round activity which also attracts tourists enhances its importance. The winter low in Chatham's employment is 45 percent of the summer high, a less extreme seasonal cycle than any other town on the outer Cape except Orleans.

Land Use

As both year-round and seasonal populations have grown, Chatham's residential land area has expanded from 9 percent of the town in 1951 to 16 percent in 1971 (Tables 1-F4 and 1-F5). Most of this increase was taken from agricultural land. Between 1970 and 1975, the number of residential dwelling units grew by almost 18 percent (Table 1-F6). Five percent of the town's area is used for recreational land, the highest percentage on the Cape. The developed saltwater beaches and golf courses that make up this part of town have already been mentioned as a strong attraction for vacationers. Much of Chatham is wetlands (6,930 acres, 44 percent of total land area), but a smaller part of the township is forested (3,718 acres, 24 percent of land area). The distribution of these land types is shown in Plates F-1 through F-3). Less than 10 percent of the National Seashore lies within Chatham, and the Seashore covers a smaller proportion of the town area than any other town on the outer Cape (Table 1-F1).

Town officials express concern that Chatham has grown too fast in the recent past. Residential and commercial areas are expected to grow into the remaining open land and at low density in forest land. Controlled moderate growth that will maintain the character of the community is desired.

The town has very active town and private conservation efforts that have sought to preserve open lands and wetlands. Chatham's widespread commitment to conservation and moderate growth should enable the town to fulfill its goal of preserving the character of the town.

Summary

Rapid development of many of the towns on the outer Cape between 1951 and 1976 has made problems of environmental quality an important issue. Local residents, both year-round and seasonal, have a clear interest in preserving the natural beauty of the area and in maintaining some areas for public recreation. Visitors from Massachusetts and from farther away also have concern for the area as a vacation site. The present distribution of land use in the six towns varies, but all have a high percentage of undeveloped land in the form of forests, abandoned farms and pastures, wetlands, and beaches. Such natural areas declined as a part of the outer Cape from 95 percent in 1951 to 83.6 percent in 1971, and development between 1971 and 1976 continued to decrease in such areas (Tables 1-F4 and 1-F5 and Plates F-1 through F-3).

Study Procedure

Sources used for this section include published material, maps, interviews, and personal observation. The publications consulted are listed in the references. A set of maps showing general classes of land use in 1971 were prepared for the six towns of the outer Cape.

The maps and general discussion of land use in each of the towns are based primarily on "Remote Sensing 20 Years of Change in Barnstable, Dukes, and Nantucket Counties, Massachusetts, 1951-1971," a report prepared by W.P. MacConnell, N.A. Pywell, D. Robertson, and W. Niedzwiedz at the Massachusetts Agricultural Experiment Station, College of Food and Natural Resources, University of Massachusetts at Amherst. The information provided in the MacConnell study is based on surveys conducted in 1950 to 1951 and 1970 to 1971. This land-use data has been supplemented by more recent data on population, employment, and changes in housing. Published data and personal interviews with town officials and people at the Cape Cod Planning and Economic Development Commission provided further information. The Cape Cod Planning and Economic Development Commission has compiled much useful data from federal, state, and town sources; this information was particularly helpful in updating the MacConnell study to 1975-1976. Federal and local regulations were consulted in preparing the section on land-use regulatory mechanisms.

PROJECTED GROWTH

Introduction

This section discusses anticipated changes that will influence land use on the outer arm of Cape Cod over the next 50 years. Projections are prepared for Cape Cod as a whole (Barnstable County), for each of the six towns from Provincetown through Chatham, and for the Cape Cod National Seashore. Where practicable, future growth and development are divided into the first 25 years (1977 to 2002, although 1995 is used in some cases) and the second 25 years (2002 to 2027).

Any attempt to project population, land use and other trends for 25 or 50 years in an area such as Cape Cod will be subject to controversy. A half century encompasses two generations of people, and it is impossible to determine precisely the factors that will affect birth rates, second-home construction, movements of retired people and other elements of growth. Extrapolation of past trends can easily be inaccurate if the basic determinants of those trends change.

Environmental constraints on future development of Cape Cod include adequacy of pure water sources, capacity of soil for septic disposal, and availability of undeveloped land. Because of these constraints, most towns on outer Cape Cod can expect to reach saturation population levels within the next 50 years. Most townspeople express a desire to promote economic prosperity, which in the past has depended largely on the growth of seasonal activities, while at the same time preserving the unique character and the environmental quality that has made their towns attractive places in which to live.

Future growth of the outer Cape will depend on such continuing trends as building of seasonal second homes, movement of retired people to year-round residences, and provision of support services for both year-round and summer-visitor populations. Many of these trends will be affected by environmental constraints, and some specific problems such as flooding, shoreline erosion, and sedimentation will affect the location of future development.

Population Growth

General

Although there are no estimates for the population of the northeastern United States megalopolis for the next 25 and 50 years, the U.S. Census Bureau has projected high, mid-range and low populations for the entire United States to the year 2050. If these projections are indicative of growth in the Northeast, they may be used to indicate percentage growth.

The mid-range projection for population in the year 2000 is 260.4 million, about 21 percent higher than the 1976 population, increasing in the year 2000 at an annual rate of 0.5 percent per year. The high estimate would be a population in 2000 that is about 31 percent higher than in 1976; the low estimate is about 14 percent higher than in 1976. By 2027, the high, mid-range, and low population projections would be 31, 21, and 3 percent higher than equivalent projections for the year 2000. All these estimates are for much slower growth than predicted for Cape Cod's winter population in the Herr report (Herr and Associates, 1976), although a few individual towns have lower projected growth. Again, long-term population projections are always subject to high error factors.

Barnstable County

Some of the uncertainties that might impair the accuracy of population projections for 25 and 50 years have been mentioned above. Most environmental constraints such as available land and water quality were considered in the Herr report in determining the saturation level of summer population in Barnstable County and the individual towns. Radical changes in type of dwelling units such as apartment buildings rather than single-family houses could extend population levels on the limited land available. However, community opinion in most towns is opposed to any change in the basic style of development that would alter the highly valued character of the communities. The projected saturation level for winter population is to be reached before 2027 for all but one of the towns in the study area.

The winter figure is lower than present summer populations and seems likely to be environmentally supportable. Even before the summer population is limited by environmental constraints, the desire to retain traditional activities and community interactions may limit further summer expansion.

The methodology and assumptions underlying the projections in the Herr report have not been repeated here in detail; the interested reader may consult the Herr report for a complete description. The saturation levels and dates listed in our tables use the Herr assumptions of relatively small average household size and approximately the same proportion of year-round to summer housing.

Based on the Herr report, Barnstable County can expect a population level in 1995 of about 187,000 year-round and 570,000 during the summer (Tables 1-F7 and 1-F8). (The tables referred to are located at the end of the section). These figures compare to estimated 1975 populations of 128,000 year-round, 380,000 in the summer. The year-round population is expected to include about the same proportion of people over 65 years old (20 to 21 percent) as was the case in 1975.

By 2027, the overall population of Cape Cod is projected in the Herr report to be at about saturation level, despite some available space for development in two towns (Mashpee and Truro). The saturation date is given as 2001 (Table 1-F9), when winter population is expected to reach about 330,000. Total summer population is projected to be about 745,000 by 2027.

Outer Cape

According to the Herr report, the six towns on the outer Cape will reach their saturation levels of population by 2047. The proportion of land available for development in 1975 ranges from almost none in Provincetown to perhaps 20 percent in Truro. A few individual towns will have virtually reached saturation level by 1995, but most will continue to grow during the second 25-year period. In 1995, the winter or year-round population on the outer Cape is expected to reach 30,000 while summer population, given the continuation of present trends, may be 123,000.

By 2027 growth will be almost completed in all towns except Truro if the Herr projections are correct and if there are no major changes in zoning and building regulations or in sewage treatment processes. With a higher proportion of houses occupied year-round, permanent population will be 49,700 and summer population 143,000.

Future Land Use

Barnstable County

General

Barnstable County (Cape Cod) will continue to fulfill a special role in the Commonwealth of Massachusetts. With careful planning, Cape Cod's importance as a center of tourist activities can be combined productively with preservation of its unique natural characteristics.

Water Supply and Sewage

Water is necessary for growth in any area. Cape Cod's water supply is obtained from the groundwater aquifer underlying the peninsula, and there are no practical alternative sources. The future development of Cape Cod therfore depends on the quantity and quality of its groundwater.

The Cape's groundwater resource is also important in maintaining the quality of the recreational surface waters that are vital to future economic development. Hydrologically, almost all fresh surface water on Cape Cod is directly connected to the groundwater aquifer. Seepage of groundwater containing high levels of nutrients into ponds and streams can result in algal growth and accelerated eutrophication, reducing their attractiveness. While open coastal areas are not sensitive to groundwater seepage, salt water embayments are.

An acceptable means for disposing of sewage and solid wastes is also a prerequisite to future growth. At the present time the vast majority of all sewage is treated, either on-site or at centralized facilities,

and recharged to the same groundwater aquifer on which the Cape is totally dependent for drinking water. Solid wastes, including septage pumped from on-site septic systems, are dumped in landfills. Leachate, the highly concentrated effluent resulting from landfills, is also recharged into the same aquifer.

There are some technological alternatives to the waste disposal problem, including ocean discharge of wastewater treatment plants and incineration or ocean dumping of solid wastes. Given the patterns of development projected for the Cape, however, it is very unlikely that these solutions will play a major role in waste handling in the future.

Thus, Cape Cod faces a clear conflict of competing uses for the same valuable resource, the groundwater aquifer. Careful planning and control of development will be required to accommodate the requirements for both water supply and waste disposal.

Many studies dealing with various aspects of water resource issues on Cape Cod have been conducted recently. Of particular interest to communities concerned with the potential impact of future development on these resources are the Barnstable County 208 Wastewater Management Program, prepared by the Cape Cod Planning and Economic Development Commission, and the 303e State Basin Plan, developed by the Department of Environmental Quality Engineering. For more detailed evaluations and discussions of concepts introduced here, refer to these studies.

The communities of Barnstable County should take steps to protect their groundwater resources while at the same time providing for the safe disposal of wastes. These steps should include an estimation of future water supply needs, acquisition of sufficient well sites to fill the anticipated need, and protection of recharge areas for existing and future wells.

The greatest threat to water supply protection posed by the type of development anticipated on the Cape is groundwater contamination with nutrients, particularly nitrates, as a result of waste disposal. While landfills are of real concern, there are relatively few of them. Recharge from septic systems is much more dispersed and therefore more difficult to avoid. While levels of contaminants are still relatively low in the Cape's aquifer, increases have been detected in recent years. Once an aquifer becomes contaminated, it is virtually impossible to reverse the situation, and treatment for use as drinking water is extremely expensive (in the same cost range as desalinization). In order to avoid long-term buildup of nutrients, the use of septic systems should be limited in areas contributing recharge to water supply wells. This can be done by sewering or by limiting development to densities of no more than one dwelling unit per acre.

Similar regulation of development along the shores of ponds and salt water embayments is also recommended. A buffer zone of 50 to 100 feet along the shoreline is recommended to provide additional protection from runoff of surface water bodies.

The legal and political intricacies of implementing water quality management programs have been extensively studied. It is recommended that the reader refer to Chapter 5 of the Barnstable County 208 Wastewater Management Program Draft Report for a detailed recommendation of controls to protect water supply and recreational waters. In addition, the Department of Environmental Engineering Quality has developed the 303e State Basin Plan.

An important part of any groundwater protection program is the enforcement of strict regulations regarding the use of septic systems for the disposal of sewage. While some of the more densely populated areas of the Cape either have or are planning sewer systems, most areas, particularly on the lower Cape, will continue to be served by septic systems.

In areas where there is no need to protect the groundwater for use as a water supply, there may be public health reasons for regulating the use of on-site wastewater disposal systems. Proper operation of on-site systems is essential to prevent public nuisance and potential health hazards from seepage of insufficiently treated wastes.

Two types of septic systems must be managed in Barnstable County. Perhaps the most troublesome are existing systems that are substandard and frequently do not function properly. The second major type includes those that have been installed in recent years and met state sanitary codes but, because the Massachusetts codes were just updated in 1977, are already substandard in one or more respects.

The major problem with most individual systems is a lack of maintenance before malfunctions occur. It is important to note that "functioning properly" does not mean simply that the wastes disappear into the ground. While a system may provide for hydraulic disposal of the wastewater, it may not provide adequate treatment. This type of malfunction poses a threat to the use of underlying groundwater for water supply. To the general public, systems are considered to be malfunctioning only in the extreme case when sewage backs up into the home or yard. In these extreme situations, failing systems are a public nuisance and a threat to public health as well as a serious threat to the water supply.

It is often difficult to correct malfunctioning systems because of poor soils and small lot sizes. The provision of sewers is frequently the best solution for areas with high septic system failure rates. Alternative types of sewer systems such as septic effluent systems may prove more economical than conventional gravity sewers, depending on local conditions.

Maintenance of on-site systems is essential, and communities wishing to avoid the costs of extensive sewering should take a more aggressive role in on-site wastewater systems management.

An important aspect of septic system maintenance is the periodic pumping and disposal of septage, the solid waste from on-site septic systems.

At the present time the Cape has no facilities for properly treating and disposing of septage. If on-site systems are to become a permanent solution to the county's wastewater problems, provisions must be made for providing septage treatment on either a town-by-town or a regional basis.

There has been extensive work over the past few years by developing management systems. The two main components of these systems generally include provision of a septage treatment and disposal facility and a program of periodic inspection and pumping. Replacement of substandard systems, particularly cesspools and clogged leach fields, is also essential. Initial public opposition to municipal management of privately owned systems may be a problem. However, if the alternative of costly municipal sewering is clearly explained, opposition should decrease. The Barnstable County 208 Wastewater Management Program will make specific recommendations of on-site systems management programs.

Zoning

Each township is responsible for its own zoning bylaws, but a number of Federal and State regulations modify the powers of towns as explained in the section entitled "Land-Use Regulatory Mechanisms." The Cape Cod Planning and Economic Development Commission provides data from special studies as well as opportunities for discussion. It plans on a county-wide basis although it has no power to influence zoning directly.

Tourism

Cape Cod has depended heavily on tourist activity to support its economy in the past and probably will continue to do so in the future. Direct services to tourists and summer residents bolster the economy, and the building of summer houses has sustained the construction industry.

The attractions of Cape Cod for tourists are many: hiking and other outdoor recreation activities, natural scenary, historic sites, water sports, and special events. Individual towns and the Cape Cod National Seashore have a variety of special characteristics and recreational facilities that draw visitors, especially in the summer. Because the Cape's attraction to tourists is based on the natural beauty of its beaches, wetlands, and countryside, environmental quality will continue to be vitally important. However, erosion and sedimentation along the eastern shore of Cape Cod will forcefully modify some tourist sites as described later in this section.

Land Use and the Environment

Land use on Cape Cod can be expected to continue changing in accordance with past trends, responding to increases in population (seasonal and year-round) as well as to the growing number of short-term visits by tourists and other economic changes. Land protected by the Cape Cod National Seashore and wetlands preserved by State and local regulations will remain undeveloped. Other open and agricultural land and forest land will gradually be converted to residential use. Some growth in business and commercial areas can be expected in most towns. In towns

such as Chatham, areas are being purchased by the town or by individuals and donated to the town for conservation and watershed areas. In the future some land will be preserved in its natural state, but a higher proportion of total land area will inevitably be developed.

Transportation

Transportation will continue to be dominated by the highway system, specifically Routes 6 and 28. Eventually, Route 6 will be a divided highway of four or more lanes for its entire length.

Railroad lines (one from Bourne to Falmouth, a second from Sandwich to Dennis and Hyannis) may be repaired and improved, but additional restoration of abandoned tracks to the outer Cape seems unlikely at this time. Inactive tracks are more likely to be paved for use as bicycle trails. Negotiations for such a conversion are currently being conducted.

It is unlikely that more large airports will be built. The existing major airports at Provincetown, Hyannis and Otis Air Force Base and smaller private airports in other towns will continue to provide local service.

Flooding

Its location and topography make large areas of Cape Cod vulnerable to flooding during ocean storms. The physical danger of building in such areas and the relevant restrictions incorporated in the Flood Plain Insurance Act will constrain future devleopment in the Cape's flood zone.

On a long-term basis, the expected erosion of the beaches along the eastern edge of Cape Cod and deposition along the northern edge of outer Cape Cod (see section D, "Shoreline Changes") will further alter development in the future.

Conclusions and Recommendations

Because of past development trends and the expressed preferences of town officials, Barnstable County will continue to grow as a tourist center, catering to both short- and long-term visits. At the same time, efforts will be made to strengthen its year-round economy. The gradual lengthening of the tourist season should help to reduce the cyclic nature of economic activity, but attracting clean, light industry is likely to depend on many variables outside the control of individual communities. Certainly the planning coordination of the Cape Cod Planning and Economic Development Commission should be helpful in the future.

Environmental considerations are likely to become even more important in future development than they are today as pressures on environmental quality increase. Population density will grow, demands on water resources will become heavier, and shoreline changes will affect present recreational areas. Areas along the shore that are subject to flooding and erosion should be avoided by developers, and tourist activity areas and residential housing should be planned with these areas in mind.

Improvements in the Cape's transportation system, particularly in roads and highways, will be necessary to ease the flow of traffic in the summer. Traffic jams at the bridges over the Cape Cod Canal will worsen unless public transportation carries a larger proportion of people to and from the Cape or unless the peak traffic times can be extended. Also, more bicycle and hiking trails should be provided on many parts of the Cape.

Provincetown

General

Provincetown, at the tip of Cape Cod, has less unused space for growth than any other town in the study area. Almost all of its undeveloped area is controlled by the National Park Service, and the town center is very densely populated. Provincetown's reliance on the ocean-related activities of fishing and tourism is likely to continue in the future.

Population

According to the Herr report, Provincetown is already near saturation population levels in terms of land available for development and capacity of the area to provide pure water. Population is expected to increase to 4,600 year-round and 20,000 during the summer by 1995 (Tables 1-F7 and 1-F8).

By 2027, these figures will grow only slightly to 4,900 year-round and 21,400 in the summer. The year-round population is expected to constitute about the same proportion (23 percent) of the summer population throughout this period.

Tourism

Tourism will continue to be a major stimulus to Provincetown's summer economic activity. Town officials are very concerned about the high winter unemployment and are in favor of expanding year-round employment, preferably in the form of small, nonpolluting businesses. At the same time, they recognize the need to preserve remaining open spaces, particularly waterfront areas, to maintain the environmental values that attract tourists.

Provincetown's beaches are expected to be areas of deposition and growth so tourists will continue to enjoy abundant water and shore recreation facilities in Provincetown. Accretion is anticipated in the north shore areas now bordered by a jeep trail and along Race Point Beach (see Section D "Shoreline Changes"). In addition, some historical buildings endangered by erosion might be moved to Race Point Beach. Provincetown seems likely to add rather than lose areas attractive to tourists in the coming 50 years if growth within the developed area of town is controlled.

Land Use and the Environment

A small amount of urban growth may take place over the next 25 years, but Provincetown has very little town-controlled land suitable for development.

Relatively light-density residential areas may become more dense, and highway and downtown commercial areas may expand slightly to meet tourists needs.

Land use patterns are unlikely to change significantly between the turn of the century and 2027. Only a slight increase in population is expected, and little further development in residential areas seems likely. Some single-family housing might be replaced by condominiums to create higher density residential areas, but the freshwater supply will limit this sort of growth.

Transportation

The basic network of transportation in Provincetown is unlikely to grow substantially in the next 50 years. Some improvements in traffice flow might be implemented by creating more one-way streets and closing some downtown areas to automobiles. Also, bicycle, hiking and jeep trails may be added to the National Seashore area to enhance tourist use.

Water Supply and Sewage

Drinking water for approximately two-thirds of Provincetown's residents is supplied by the Provincetown Water Department, which also supplies water to a limited area of North Truro. The remainder of the community is dependent on private wells.

Only on-site systems are used for sewage disposal and many of these are very old cesspools which provide little or no treatment. Around the harbor area the groundwater table is so high that cesspools are flooded during high tide, which directs transport of insufficiently treated waste to the harbor.

Many of Provincetown water company's wells are located in the town of Truro within the jurisdiction of the National Seashore. Provincetown has had difficulties in the past in negotiating agreements for the installation of wells in Truro. One concern is the possible lowering of groundwater levels, making private wells in Truro more costly. Because of development restrictions imposed by the National Park Service, the quality of water is genrally not an issue.

To protect private wells, minimize potential public health risks, and protect surface water quality, wastewater management should be a high-priority concern in Provincetown. Contamination of the harbor as a result of present and future development could severely threaten economic growth. Most studies indicate that some means of sewering will be necessary in the more densely populated sections of town.

Zoning

Provincetown is in the process of a major revision of its zoning bylaws and the book describing the new system will not be printed until the Attorney General approves it. The new zoning will include commercial,

noncommercial and several residential categories. Provincetown has no master plan for development.

Flooding

Provincetown has received final maps of the elevations for the new flood plain designation, unlike most Cape Cod towns which have only emergency maps. The area most affected extends from Wood End Light, on around Long Point and Provincetown Harbor and then inland through the Pilgrim Beach area. Much of the marsh inland from Race Point is also in the flood zone.

Conclusions and Recommendations

The constraints on further development in Provincetown include scarcity of land available for development, a precarious water supply, problems with waste disposal, and extreme seasonal traffic problems. Because of these constraits, in 1976 the growth policy committee urged that the town pursue a strict limited-growth policy. Such a policy should include careful consideration of the best use of available land and open space and special care to preserve attractive features of the waterfront area. The danger of flooding along most of the harbor and adjacent beaches provides another incentive to limit development in that area. Much of the effort to improve the town's economy in the future will have to concentrate on what is already there: helping the fishing industry, spreading the impact of tourism throughout the year, and redesigning present land use as necessary to ease the flow of traffic and to encourage year-round activities.

Truro

General

Truro's large areas of undeveloped land provide a dramatic contrast to Provincetown's crowded town area. Development in Truro is expected to continue into the middle of the twenty-first century, with saturation populations substantially larger than present ones. The town includes much acreage within the National Seashore, which will continue to protect its beaches, wetlands and woods from development.

Population

Truro's population is expected to grow steadily throughout the next 50 years and beyond. By 1995 population may be 17,000 in the summer (43 percent higher than in 1975) and 2,100 in the winter (50 percent higher than in 1975). Winter populations will probably remain only about 12 percent of summer levels (Tables 1-F7 and 1-F8).

In the second 25-year period, year-round population may grow at a more rapid rate than summer population to about 5,000 in the winter and 21,600 in the summer by 2027. By that time, Truro's year-round and summer populations will be larger than Provincetown's populations.

Tourism

Tourists, both long-term summer visitors and short-term recreation seekers, will continue to be the main-stay of Truro's economy. Major commercial areas in the neighboring towns of Provincetown and Wellfleet will continue to serve Truro's residents. The large proportion of undeveloped lands and the attractive rural atmosphere of Truro are likely to become more striking in contrast to neighboring towns with much earlier saturation dates. Development will remove some open areas over time but with proper planning many will remain.

Some popular beach areas in Truro within the boundaries of the National Seashore will be affected by erosion over the next 50 years. Those that will suffer the worst erosion lie along Ballston, Longnook and Highland beaches. Head of the Meadow Beach will remain relatively unchanged except for some growth on the non-ocean side. Tourism should not be affected for these beaches, but parking lots and other tourist facilities should be appropriately planned.

Land Use and the Environment

Expansion of residential areas in the next 25 years will be steady and will probably absorb much of the agricultural and open lands (abandoned fields, heath and sand). Because of reliance on commercial facilities in the neighboring towns of Provincetown and Wellfleet, Truro's urban growth will probably be moderate.

Residential development will continue in the second 25 years, perhaps extending into undeveloped forested areas. Because of the rapidly declining amount of land available for development in other towns on the outer Cape, Truro may experience an acceleration of growth in this second period. The nature of development is likely to continue to be residential, however, with only modest commercial and urban growth. Residential density will probably continue to be light to moderate, in contrast to the denser development of Provincetown.

Transportation

Many secondary roads will be added to Truro's transportation network to service new housing developments, but the major highway will probably not change much. A new road to Highland Light is planned by the Park Service. A bicycle/hiking trail is planned all along the shore and at places inland from Head of the Meadow Beach to Ballston Beach and into Wellfleet.

Water Supply and Sewage

Except for a small section of North Truro served by the Provincetown water department, the town of Truro is totally dependent on private wells for its drinking water supply. Sewage disposal is processed exclusively by on-site systems.

In the short term, it is clearly important for the town to provide adequate management of on-site systems if it is to avoid groundwater contamination that would eventually make the provision of municipal water to large segments of the community a necessity. Truro is fortunate to have substantial acreage within the National Seashore. If it should become necessary to develop a municipal water supply, the National Park Service's restrictions on development ensure that sufficient groundwater relieves the community of the need to reserve land for eventual development of well fields. However, if the need for municipal water and sewer services is to be avoided, steps should be taken now to control the rate and type of development that depends on on-site wastewater disposal systems.

Zoning

Truro published a compilation of zoning bylaws in 1974, but there have been several revisions since then. A new set of bylaws reflecting these revisions was being drawn up in 1978. The basic classification are limited business, general business and residential. New residential lots must be three-quarters of an acre, but smaller preexisting lots are allowed in some places. No commercial zoning is included in the town. A master plan prepared for Truro in the 1960s is now out of data; at present no replacement is planned.

Flooding

Truro has rejected the designation of the flood areas determined by the Corps of Engineers. Nonetheless, the flood areas along major estuaries will probably inhibit development in those areas.

Conclusions and Recommendations

Truro's relatively undeveloped state allows much more leeway in planning future growth than most towns on the outer Cape enjoy. The abundant land can be developed while maintaining the town's unspoiled character. Present three-quarter acre zoning should encourage this. The wetlands and the areas within the boundary of the National Seashore should help to provide needed open space even when development has advanced substantially. As in other towns, special care should be taken to steer construction away from areas subject to flooding or erosion and to protect unique areas outside the park boundaries. The long period of development ahead for Truro should help keep its economy healthy with both construction and tourist-associated activities.

Wellfleet

General

Wellfleet, at about the midpoint of the outer arm of Cape Cod, combines an attractive central commercial district with a variety of historical and natural areas. In addition to its developed section, Wellfleet has extensive undeveloped areas both inside and outside the boundaries of the National Seashore.

Population

Wellfleet's population is expected to grow at a moderate rate for the next 25 years, with about a 40-percent increase between 1975 and 1995. The summer population in 1995 is projected to be about 19,000 with a year-round population of 2,800 (Table 1-F7, 1-F8 and 1-F9).

By 2027, Wellfleet is projected to reach its saturation level of population: 7,800 year-round and 20,000 in the summer. A higher proportion of the population then will be year-round.

Tourism

Tourism will continue to be an important part of Wellfleet's economic base, and Wellfleet's role as a local center of commerce for summer visitors as well as year-round residents is expected to continue. The marina and other facilities of the harbor area will continue to attract tourists. If improvements are made in road access to the Duck Harbor-Griffin Island-Great Island area, more tourists can be expected to go there.

Land Use and the Environment

The next 25 years will bring further development of Wellfleet's forested land for residential areas. Available land and assumed construction rates shown in Table 1-F9. The traditional town-center commercial area will expand slightly, while some additional semicommercial development such as convenience stores and fast-food restaurants will most likely be located near the newer highway facilities to serve visitors. Land use projections for 1995 are shown in Table 1-F10.

In the second 25 years, residential construction will probably be slower, but more people are expected to maintain year-round instead of seasonal residences. Commercial land use may not need much expansion to meet this change, but more shops and other service businesses will probably stay open year-round to meet the needs of the increased winter population.

Transportation

Additional access roads to residential areas and to areas surrounding the harbor (for example, the Duck Harbor-Griffin Island-Great Island area) may be added. Improvements could also be made along Route 6 and to traffic patterns through town. The Park Service is contemplating building a short system to serve the Camp Wellfleet area and providing parking near Route 6. The planned hiking and bicycle path in the National Seashore will extend the length of Wellfleet with at least two access paths to Route 6.

Water Supply and Sewage

Because of Wellfleet's complete dependence on private wells for water supply, protection of groundwater quality is particularly important. Sewage is exclusively processed by on-site systems.

Studies have identified Wellfleet Harbor as an area of critical concern with regard to sewage disposal. During summer months the overload from too many septic systems is a potential threat to public health and a real threat to the aesthetic quality of the area. Consideration of alternative sewer systems would be appropriate for this area.

In addition to addressing the more immediate problem of wastewater management in the harbor area, the town of Wellfleet should develop an on-site wastewater management program to protect its groundwater. Such a program might make it possible for the community to avoid the expense of providing municipal water and sewers in the future.

As with Truro, should the provision of municipal water become necessary, the presence of the National Seashore with its ban on development ensures that sufficient high-quality water will be available.

Zoning

Wellfleet's zoning bylaws were updated in 1976 and no major revisions are planned in the near future. Classifications include National Seashore Park, commercial (central district), limited commercial along Route 6, residential (minimum lot size 20,000 square feet), and resort residential (allowing limited commercial, travel and leisure activities while maintaining rural environment). No master plan exists. Some of the older sections of town have denser residential development than is expected in the future development areas.

Flooding

Extensive areas of Wellfleet Harbor and its surrounding estuaries are subject to flooding during hurricanes and other storms. While those include some undeveloped conservation and wetlands areas, flooding may also affect some areas already developed.

Conclusions and Recommendations

Wellfleet has substantial growth potential in terms of land available for development, but some environmental problems in the Wellfleet Harbor area are already noticeable. Alternative systems for this area should be considered in the near future. Additional roads and a hiking/bicycle trail would be particularly useful during the summer season. The character of the downtown area should be preserved for both year-round and summer residents. Implementation of several plans to improve visitor areas within the National Seashore would also enhance Wellfleet's future development. Future development should be avoided in harbor and ocean areas subject to flooding or erosion.

Eastham

General

Eastham, although smaller than most towns on Cape Cod, has a substantial amount of space for further growth. Its popularity as a beach area is likely to continue in the future. As an attractive, homogeneous residential community, Eastham will continue to draw summer people as well as year-round residents.

Population

If Eastham's population growth is slightly slower than that of the past 20 years, population should reach about 5,400 in the winter and 23,000 in the summer by 1995 (Table 1-F7 and 1-F8).

In the second 25 years, summer population will expand more slowly to 28,000 in 2027, and the winter population will continue to grow at its present rate to 11,000 (Tables 1-F7 and 1-F8). By 2027, the winter population may be close to 40 percent of the summer population, in contrast to 19 percent in the mid 1970s.

Tourism

Eastham's economy is likely to retain its traditional dependence on seasonal residents and short-term visitors despite the growing importance of year-round residents in the second 25 years. Eastham's many historical sites will continue to attract visitors.

Both Nauset Beach and Coast Guard Beach may lose more than 100 feet to erosion over the next 50 years. The erosion is likely to destroy parts of roads and parking lots and to wash out areas along the tops of banks where houses are now located. Therefore, several tourist-service patterns within the National Seashore will have to be altered.

Land Use and the Environment

Although little open area remains, Eastham has forested areas that will be developed as residential lots (Table 1-F10) throughout the next 25 years. Although Eastham is small in area, substantial unused acreage in private hands allows considerable expansion of developed areas. The areas within the Seashore boundary will remain natural. The additional commercial/urban growth expected along the highway is unlikely to result in any relative decline of commercial centers in neighboring Orleans and Wellfleet.

The second 25 years will probably be characterized by slower expansion of summer residential areas and gradual increase in the number of year-round residences. Commercial development along the highway will probably continue to serve increasing numbers of short-term visitors even after the growth of seasonal population has leveled off.

Transportation

The highway through Eastham could be widened to increase its capacity to handle summer crowds. Bicycle and hiking trails have been proposed within the National Seashore, and a horse trail may be added between Marconi and Nauset beaches. Roads and parking areas near the ocean beaches will have to be moved as erosion destroys existing facilities.

Water Supply and Sewage

Because Eastham is completely dependent on private wells for water supply, protection of groundwater quality is particularly critical. Sewage disposal is exclusively by on-site treatment and subsurface recharge.

With proper maintenance of on-site systems, Eastham may avoid the expense of providing municipal water and sewage services. At this time many summer homes have both private wells and sewage disposal systems on very small lots. These systems appear to be adequate as long as they are used only seasonally. If extensive conversion to year-round occupancy occurs in these areas, it may be necessary to provide sewage collection to protect ground water quality. In the event such services are required, consideration should be given to the use of a septic effluent collection system with centralized soil absorption.

As with Truro and Wellfleet, the presence of the National Seashore with its restrictions on development ensures the availability of a municipal water supply if one becomes necessary.

Zoning

Eastham's zoning code was revised in 1976. The general residential lot minimum is now 20,000 square feet; the minimum for duplexes is 30,000 square feet. Some wetlands and conservancy districts are provided. There is strip zoning along the highway for commercial/business and some permissive use. People feel that residential quality has gradually improved in recent years, and the medium density required by the present zoning code should encourage good-quality residential areas in the future.

Flooding

Large areas along the Herring River estuaries, other estuaries and Nauset Beach are vulnerable to tidal flooding in storms and hurricanes. Final elevations designating the flood plain are not year available for Eastham, but the preliminary assessment by the Corps of Engineers does indicate that some areas should be restricted from future development.

Conclusions and Recommendations

The presence of large undeveloped areas within the National Seashore guarantees a safe watershed area for Eastham should a municipal water supply become necessary in the future. In terms of residential development,

the existing system of private wells should be adequate until year-round population is much larger than at present. Despite problems with summer traffic congestion and possible difficulty in complying with Massachusetts waste disposal regulations, Eastham should be able to continue its economic growth while providing both tourist recreation and adequate land conservation. It is important that the density of new housing continue to be controlled and that development of areas subject to erosion or flooding be avoided. With these considerations in mind, town officials and the Park Service should be able to maintain Eastham's unique character and appeal in the future.

Orleans

General

Orleans has been a popular area for year-round and seasonal residents on Cape Cod for a long time. Its many water-based natural attractions and recreational facilities are less dependent on the National Seashore than most of the towns to its north. Active town government has contributed to its steady appeal and has helped avoid some of the disadvantages of rapid growth.

Population

The population of Orleans will continue to grow at a moderate rate for the next 25 years. Winter population is projected to grow form its 1975 level of 4,400 to about 7,200 by 1995; summer population is expected to increase from 11,500 to 18,000 (Tables 1-F7 and 1-F8). If present trends in construction and density continue, saturation level of population will be reached at about the turn of the century.

The second 25 years may be marked by continued moderate growth, possibly to a year-round population level of 11,000 and a summer level of 25,000 by 2027. This will require a denser pattern in residential areas than that assumed in the saturation projection.

Tourism

Although the tourist industry is important in Orleans, its commercial services for neighboring towns provide steadier year-round employment than exists in many other towns on the outer Cape. Orleans' special recreational facilities should continue to attract regional residents both in summer and in winter. Erosion is expected to shift Orleans Beach to the west over the next 50 years and to alter the configuration of the eastern part of Pleasant Bay. Despite these shifts, water recreation will continue to be a popular tourist activity in Orleans.

Land Use and the Environment

Changes in Orleans' land use over the coming 25 years are likely to be subject to many of the same constraints faced by Chatham. Undeveloped

forest will be converted to residential areas, but virtually all undeveloped wetlands should remain as natural areas because of laws protecting them. Commercial/industrial areas are likely to grow somewhat during this period. By the end of the twentieth century, very little open land suitable for development will remain.

In the second 25-year period there might be increasing density of residential development and growth of urban/commercial areas in malls or shopping centers.

Transportation

The mid-Cape highway could be improved to create easier access to Orleans for off-Cape visitors. Summer traffic flow in town could be improved, probably without extensive new road systems. Hiking and bicycle trails along the old railroad right of way would be a useful addition to the transportation network.

Water Supply and Sewage

Approximately 50 percent of the town of Orleans is now served by municipal water. This percentage will probably increase as the population grows. While portions of Orleans are protected from future development by the National Seashore, detailed studies should be conducted to determine whether additional watershed protection areas should be designated.

At the present time, all sewage is processed by on-site systems. During summer months the frequent system failures in the most densely populated section of the town are a public nuisance and a potential threat to public health. Studies are currently underway to determine the most economical solution to this wastewater management problem. The community should address the issues of on-site management for areas that will not be served by any proposed sewer system.

Zoning

Orleans' relatively stable zoning system has kept most townspeople pleased with the development of the town except for some small areas of over-intensive business zones. The last major revision of zoning took place early 1976, but one additional district classification, "marine business," was added later that summer. The other classifications are rural business, limited business, general business, commercial (wholesale businesses, light industry), conservancy, seashore conservancy (Nauset), and residential (minimum lot size 40,000 square feet). Although the town is not actively trying to purchase land for watershed protection, Orleans does accept gifts of land for conservation districts.

Flooding

The area in Orleans most likely to be subject to flooding during storms or hurricanes are low-lying borders of Pleasant Bay and its estuaries and Namskaket and Little Namskaket creeks and their surrounding marshes.

Conclusions and Recommendations

Orleans has managed to retain its pleasant character throughout its fairly rapid growth of the past 25 years, and there is no reason to expect a change in the future. Continued interest in conservation control and strict zoning will be necessary to preserve the attractive environmental setting of the community. Development should be avoided in areas subject to flooding or erosion. Traffic control will need to be improved, perhaps by setting up new traffic flow directions and adding a few connecting or access roads. A sewer system is likely to become necessary as population reaches the saturation point. Orleans should certainly by able to retain its attraction both as a residential community and as a local business center.

Chatham

General

Chatham, the largest township on the outer Cape, combines a heavily populated downtown area with extensive water-oriented recreation and natural areas. The National Wildlife Refuge on Monomoy Island and Nauset Beach within the Seashore boundary are unique natural areas. Chatham's very fast growth over the past 25 years can be expected to slow down as saturation levels are approached.

Population

Chatham's population is now the highest of any town in the study area, but its saturation level will be lower an will be reached sooner than some other towns. Continued moderate growth has been projected to result in a 1995 population of 8,500 in winter and 26,000 in summer.

Although the Herr report predicts a turn of the century saturation level in Chatham as well as Orleans, some further population growth is expected until 2027, to 10,000 in winter and 27,300 in summer. The Metcalf and Eddy report (1976) estimated that the "most probable" development pattern would yield a year-round population of 14,000 in 2020, and the saturation level for total population would be 26,600 to 39,300 (Tables 1-F7 and 1-F8). In either case, Chatham is closer to its fullest population level than are Eastham, Truro, and Wellfleet.

Tourism

Chatham's attractiveness for tourists depends on both its Main Street commercial area and its many marine and land resources. Particular care will be required to prevent development so dense that it might detract from the character and desirability of the community. A continued substantial tourist business will depend on protecting marine resources including boating, fishing and swimming. Its commercial sections will continue to draw seasonal residents as well as short-term visitors from nearby towns.

Land Use and the Environment

In the coming 25 years, Chatham's population growth can be expected to stimulate continued development of new residential areas. The continued availability of salt-water beaches and other recreational opportunities can be expected to require additional tourist-serving facilities. Many of these will locate near existing commercial areas along the highways.

In the second 25-year period, Chatham will be beyond the projected "saturation date" and further land development is likely to be limited. There is, of course, the possibility of denser residential areas and of conversion of some residential areas to commercial. However, the high level of public concern in Chatham for preserving the town's environment and beauty will probably exert pressure to keep some areas undeveloped for watersheds and for undeveloped recreational use.

Transportation

Some improvement in summer traffic flow can be achieved by reorganizing existing road use. If the downtown area is to remain oriented toward pedestrians, some modification of traffic flow might become necessary if the amount of automobile traffic continues to increase. Few additional roads should be needed in Chatham, with the exception of small connecting roads for new housing developments. Chatham's airport will continue to provide service for small airplanes.

Water Supply and Sewage

Almost the entire town of Chatham, approximatley 96 percent, is served by municipal water. It is anticipated that all future developments will also be served. It is therefore essential that the town make adequate provision for the protection of existing and prospective recharge areas. nutrient levels in existing wells that are located within populated areas of the community should be carefully monitored. If nitrate levels increase, efforts should be made to reduce the nutrient loads within the well recharge area. (On Cape Cod it is estimated that the recharge area for a well yielding 1 million gallons per day is approximately 1.3 square miles.) In order to reduce waste loads in already developed areas, sewering must be required. Regulations on new development should be enacted to reduce the need for future sewering.

The town of Chatham has taken steps to insure that an adequate number of well sites are available for future water development. It is important to remember that these wells draw from areas much larger than those protected under State law. In particular, many of the proposed well sites located on the town boundary will draw groundwater recharged in areas outside of Chatham's jurisdiction.

Chatham is the one community in the study area that has a sewer system and treatment facility in operation. The treatment plant is quite small, with a capacity of less than 0.5 million gallons per day, and is operating

at only about one-third capacity. Limited extension of the sewer system into primarily commercial areas is planned. If the community wishes to avoid more extensive sewering, it should consider initiating an on-site systems management program.

Zoning

Chatham's zoning bylaws are more complex than those of many towns on the outer Cape. Existing lots vary from 10,000 square feet to 3 acres, but most of the smaller lots (10,000 to 25,000 square feet) are in older parts of town. In the most recent revision of the zoning bylaws, May 1977, one-half acre lots were rezoned to one-acre lots. There are, of course, commercial and business zones, and the town is actively acquiring land for conservancy and watershed protection.

Chatham's historical development has been heaviest along Route 28 and in seasonal residential areas along the coastline. Further development will be concentrated in the available land in south, west and northwest Chatham. In 1976 there were 454 approved lots (not yet built on) in proposed subdivisions, primarily in those areas.

Flooding

Chatham's extensive shoreline exposes much of the town along bays and estuaries to tidal flooding during storms and hurricanes. Final flood plain maps should be prepared by late 1978 or 1979.

Conclusions and Recommendations

Chatham's large population and reliance on a municipal water system make it particularly sensitive to the need to protect existing and prospective recharge areas. In the next 50 years, further growth of summer and winter populations will require extension of water and sewer services. The town is already acquiring land to protect watersheds and should continue to do so. New development should be kept away from flood-prone areas, most of which are already developed anyway. The major erosion areas are within the Seashore but will affect some existing houses on Nauset Beach. Growth should proceed moderately to avoid dense development and maintain the character of the community.

Cape Cod National Seashore

The Cape Cod National Seashore not only constitutes a large part of the acreage of the outer Cape, but it fills a special role, defined in the authorizing legislation (Public Law 87-126, August 7, 1961), "to assure this and future generations the opportunity to enjoy the outstanding scenic, scientific, historical and recreational resources found here and to gain a greater appreciation of this environment and man's relationship to it." Land uses permitted in the National Seashore are critical in the planning and future development of the six towns whose borders include

parts of the Seashore. Its preservation in a natural, undeveloped state is particularly important for towns that may in the future need more freshwater than their own developed areas can supply.

The Master Plan prepared in 1970 analyzes present use of the Seashore and projects 40 general nature of future development in various sections. Those general plans had not changed by 1978, but projections of specific park developments have not yet been prepared for the coming 50 years.

By 1976 the annual number of visits to the Seashore -- 5,018,707 -- had almost tripled since its opening in 1964. It is difficult to estimate future park use, however, because the increase in number of visits slowed down during the 12 years (see Table 1-F11). Estimates of future growth based on the years 1964 to 1976 give much higher projections than estimates based on 1969 to 1976. Furthermore, simple projections do not account for limiting factors such as maximum attendance levels at popular sites, capacity of highways to handle peak loads in summer and number of rooms and camp sites available for overnight visitors. With these limiting factors ignored, a simple projection of past trends would estimate two or three times as many visits by the turn of the century as in 1976 and perhaps three to four times as many by 2027. In fact, this projection is probably much too high. In addition to limiting factors already mentioned, seasonal crowding will undoubtedly keep some visitors away long before such projected levels are reached. The number of visits will also be influenced by a great many other factors, including attractiveness of other vacation sites, cost of gasoline, availability of public transportation and bicycle paths, environmental quality of the Seashore and other parts of Cape Cod, changes in popularity of various recreational activities, and seasonal timing of visits to the Seashore.

Plans for future development of the Seashore include new trails for hiking, biking and horseback riding and access roads to certain recreation areas. The plans also call for developing or improving areas with parking, interpretive and hiking trails, seasonal residences, bath houses, and comfort stations. These sites include Paradise Hollow, Atwood Higgins House, Bay Side Beach-Griffin Island-Great Island Natural area, Pamet Valley, Highland Light Complex, Cranberry Bog, Marconi Beach, Fresh Brook Village, Nauset Coast Guard Station, Skiff Hill-Penniman House Complex, and Herring Cove Beach. Eventually, hiking and bicycle trails are to extend the length of the National Seashore.

The Master Plan for the Cape Cod National Seashore also includes preliminary zoning of areas for public use and development versus preservation and conservation. The areas within Seashore boundaries have been classified according to present use, with acreage distribution as shown in Table 1-F12.

Some 85 historic structures have been designated within the Seashore boundary. The nine owned by the United States government are being developed as exhibits and museums. Others will remain in private ownership. If additional private structures are later acquired by the government, they will be preserved in the park. Interpretive programs will be set up for Coast Guard Stations or lighthouses if they become available for park use.

To increase the Seashore's potential for greater use in the future, efforts should be made to spread visits more evenly over the seasons. Many facilities could be improved and made available for "off-season" even though some water sports are practical only in warm weather.

The Seashore may acquire additional land from private holders if money becomes available. In addition to developing new areas and linkages such as short bicycle trails between rental centers, major trails, automobile beach access and connecting roads, the Park Service will have to move several existing roads and facilities because of erosion problems. Parts of the parking lot at Coast Guard Beach are already destroyed or endangered. The Old Harbor Coast Guard Station has been moved from its erosion-prone location to Race Point for exhibit. Other facilities may also have to be moved in the future as erosion and deposition change the contours of the Seashore. New facilities should be located outside the areas subject to storm flooding as illustrated in Plate F-4 located at the end of this chapter.

Summary , Conclusions, and Recomendations

The next 50 years will be marked by many changes in the six towns of outer Cape Cod. Population levels will probably reach saturation in all but one of the towns as available land is developed. Tourism will continue to be a major focus of economic activity, and the Cape Cod National Seashore will be important for preservation of natural seashore and inland spaces. New transportation facilities will be added to handle summer automobile traffic and to offer alternatives such as bicycle and hiking trails. Erosion and deposition will change most of the eastern and northern beach areas although beach use can continue with roads and parkin areas further inland than they are today.

Each town will have to control its own rate and type of development to maintain the desired characteristics of the community. Even with significant increases in population, the towns can retain some undeveloped area of the National Seashore will ease potential future problems of supplying increasing amounts of water for many of the towns. Each town should also consider the dangers of flooding in certain land areas near bays, estuaries and the ocean in determining which areas should be withheld from further construction. Zoning can help to control both location and ultimate density of development.

The outer Cape is a very special resource for the northeastern United States. With proper precautions, it will retain its unique attraction for year-round residents and seasonal visitors.

Study Procedure

The sources used for this section include published and unpublished reports, maps and interviews. Reports consulted are listed in the references.

Projections of population, employment and housing are based primarily on "Development Projections for Cape Cod," prepared for Cape Cod Planning and Economic Development Commission by Philip B. Herr & Associates, April 1976. Separate projections for specific towns such as Chatham have also been consulted and are referenced in the appropriate tables. When necessary, those projections have been extrapolated to 2027. When the saturation point has been reached before 2027, however, further growth has not been projected.

The plans of individual towns for future growth and development have been obtained from interviews with town officials; from special local growth policy committee statements prepared in 1976 on Growth Management Problems and Priorities; and from land use projections contained in "Remote Sensing, 20 Years of Change in Barnstable, Dukes and Nantucket Counties, Massachusetts, 1951-1971," a report prepared by W. P. MacConnell, N. A. Pywell, D. Robertson and W. Niedzwiedz at the University of Massachusetts at Amherst.

This letter report formed the basis for maps and general discussion of land use in the section entitled "Present Land Use."

The staff of the Cape Cod Planning and Economic Development Commission and officials of the National Park Service have also been helpful.

RECREATION

Introduction

Recreation on Cape Cod satisfies a need of the local populace, furnishes leisure activities for long-term and short-term visitors, and supports a major part of the Cape's economy.

Proximity to the large northeastern population centers a demand for the Cape's resources. Many opportunities for swimming, boating, fishing, shellfishing, bicycling, hiking and sightseeing exist on the Cape, particularly on the eastern shores where the Cape Cod National Seashore encompasses more than 25,000 acres (Massachusetts Coastal Zone Management Program, 1977).

Increasing use of the Cape's resources has engendered problems with transportation, parking and environmental quality. As stated in the regional chapter of the Massachusetts Coastal Zone Management (CZM) Plan (1977),

the Cape cannot continue indefinitely to meet most of the demand for coastal recreation in Massachusetts.

Swimming

Cape Cod's beaches are its most important recreational resource, particularly the six beaches of the National Seashore (Herring Cove Beach and Race Point Beach in Provincetown; Head of the Meadow Beach in Truro; Marconi Beach in Wellfleet; Nauset Light Beach and Coast Guard Beach in Eastham). Town beaches, for example, Nauset Beach in East Orleans and Cahoon Hollow Beach and White Crest Beach in Wellfleet can also be used by the public. Bech access is generally limited only by parking for which there is a charge.

Recent interest in surfing on the outer Cape beaches has resulted in the designation of special areas for this activity at Nauset Beach, East Orleans; Coast Guard Beach and Nauset Light Beach in Cape Cod National Seashore; and White Crest Beach, Wellfleet.

Attendance figures for the Cape Cod National Seashore beaches (Table 1-F11) demonstrate the demand for swimming on the outer Cape. (All figures referred to are located at the end of this section.) The 1975 supply and demand figures for all of Cape Cod (Table 1-F13) show the Cape's beaches can meet the demand for swimming. Furthermore, the U.S. Army Corps of Engineers and the Bureau of Outdoor Recreation estimate that the beaches on the Cape, together with those on Nantucket and Martha's Vineyard, should still satisfy the tourist and resident demand for swimming in 1990 (Southeastern New England Study, 1975). As stated in the 1975 Southeastern New England Study, however, adequate transportation and parking will have to be provided.

Boating

Several harbors adjacent to the easterly shores study area can accommodate recreational and commercial boating. Provincetown Harbor offers two piers, one boat ramp, 300 moorings, and 150 slips for boaters; approximately 40 draggers and scallopers are berthed here (Massachusetts CZM Program, 1977). Nauset Harbor is located in the towns of Eastham and Orleans. Numerous town landings are available in Town Cove and near Mill Pond and Nauset Harbor is also served by town and commercial docks. Chatham Harbor and Pleasant Bay have boating facilities in Orleans, Harwich and Chatham. The number of recreational craft (estimated by the Corps of Engineers from aerial photographs) is each of the six outer Cape towns is presented in Table 1-F14. Commercial clammers and scallopers are based in Harwich, and approximately 80 commercial fishing boats operate from Aunt Lydia's

Cove, the primary mooring location for Chatham's fishing fleet (Massachusetts CZM Program, 1977).

Recreational fishing accounts for much of the boating activity based on Cape Cod. The 1977 Massachusetts CZM Program estimated that 100 party and charter boats operate from Cape Cod harbors. Existing boating facilities cannot handle the summer crowd. The biggest problem, however, is the shoaling of bay and harbor entrances (Southeastern New England Study, 1975), a condition that occurs at Chatham and Nauset Harbors (U.S. Army Corps of Engineers, 1968 and 1969).

The high demand for boating facilities on the Cape is expected to increase, and in 1975 the demand for boating opportunities was already estimated to be 64 percent higher than the supply (Table 1-F13). Potential sites for recreational boating facilities are presented in Table 1-F15.

Fishing and Shell fishing

Fishing and shellfishing are important recreational and commercial activities on Cape Cod. For example, 14,580,000 pounds of finfish and 142,000 pounds of shellfish were off-loaded in Provincetown during 1975 (Massachusetts CZM Program, 1977). Charter and party boats are available as well as surf fishing along the entire National Seashore. No licenses are required for salt water fishing; fresh water fishing, however, is licensed. All towns require permits for shellfishing. Over 7,500 permits were issued by the six outer Cape towns in 1976 (Table 1-F16).

Demand for salt water fishing, estiamted at 80,000 fisherman days in 1970, will probably increase to 120,000 fisherman days by 1990 due to the increasing tourist volume and increased participation in salt water fishing (Southeastern New England Study, 1975). This figure understates the demand estimated in Table 1-F13.

Camping

Commercial campsites, tentsites and trailer parks are located in Provincetown, Truro, Wellfleet and Eastham. Youth hostels in Truro and Eastham provide accommodations for members.

As Table 1-F13 shows, the demand for campsites on Cape Cod in 1975 exceeded the supply by 36 percent (Massachusetts CZM Program, 1977). Existing campgrounds (1975) are expected to fulfill about a fifth of the demand expected in 1990 (Southeastern New England Study, 1975). Although more facilities are needed, their development may prove difficult because

many of the towns have zoning bylaws prohibiting new or expanded trailer or camping areas (Massachusetts CZM Program, 1977).

Off-the,Road road Vehicles

Beach buggies are permitted in certain areas of the outer Cape at specified times of the year, and dune trails have been established to minimize their impact. Dune tours are conducted by the Audubon Society (Cape Cod Chamber of Commerce, 1977).

The National Park Service maintains a system of permits and regulations regarding beach buggies and other recreational vehicles. These include restrictions on the number of vehicles allowed per day. In the summer of 1975, 2,600 permits were issued. Ecological damage and erosion caused by beach buggies are a source of concern for local towns (Massachusetts CZM Program, 1977). Driving beach buggies over the dunes can lead to accelerated erosion of the outer Cape beaches since they destroy vegetation, which exposes the dune to wind erosion.

Bicycling and Hiking

Three bicycle trails have been laidout in the National Seashore: Nauset Trail, Eastham; Head of the Meadow Trail, North Truro; and Provincelands Trail, Provincetown. Numerous hiking trails have also been established. The major trails are Nauset Marsh Trail in Eastham, the Atlantic White Cedar Swamp Trail in South Wellfleet and the Beech Forest Trail in Provincetown.

Economic Considerations

Cape Cod's economy is heavily dependent on tourists seeking recreation; 75 percent of Cape Cod's gross national product has been attributed to tourism (Massachusetts CZM Program, 1977). Nearly 75 percent of those employed on the Cape work in wholesale, retail and service trades, as shown in Table 5-17, and 85 percent of the summer wages and 15 percent of the winter balaries are paid by the tourist industry. In 1971, income from recreation-related transactions on the Cape was $76 million (Southeastern New England Study, 1975).

The towns expend money on municipal services and beach maintenance to support the recreation industry. For this reason, the towns feel strongly that differential pricing for beach use (resident/nonresident) is appropriate and necessary. The rise in taxes that accompanies increased demand for municipal services concerns many Cape residents (Massachusetts CZM Program, 1977).

The resources of the Cape must be protected and preserved to maintain tourism and the local economy. The needs of those who live on the Cape and those who enjoy visiting the Cape must be balanced.

Problems

Recreational demands have caused problems for Cape Cod Access is one of the major difficulties. Conflicting uses and overutilization are others. They may diminish the Cape's desirability and threaten its future.

Access problems affect residents and nonresidents alike when the large influx of traffic clogs the Cape's major roads (Routes 28, 6 and 6A). The popularity of the Cape places high demands on other municipal services as well. Beach access is further limited by available parking and additional parking facilities are opposed.

At present, the Cape is reached primarily by automobile and bus. In addition, two airports (Provincetown and Chatham) serve the outer Cape, and a ferry runs between Boston and Provincetown. Recommendations for improving access inlcude increased use of public transportation and development of transportation links and bicycle and hiking trails that could link beaches and other points within the towns (Massachusetts CZM Program, 1977). In these ways, large increases in traffic and parking facilities would not be required.

The exceptional demand for the Cape's recreational facilities has exerted pressure on fragile and nonrenewable resources, creating use conflicts that did not exist previously. Groundwater resources are endangered, and pollution results in occasional closing of shellfish beds. Wetlands have been threatened by expanding construction. The rising popularity of recreational boating has created competition for existing space between commercial and pleasure craft, has necessitated harbor dredging, and has contributed to harbor pollution (Massachusetts CZM Program, 1977).

As the 1977 CZM report points out, recreational activities on the Cape are also vulnerable to influence from unrelated activities. Oil drilling on the outer continental shelf could result in damage to beaches or fishing areas. The fleet required to service drilling rigs could compete with fishermen and recreational boaters for harbor space.

Present and future development of recreational facilities on the Cape must be carefully controlled to determine environmental impacts. Over-utilization or misuse could hasten erosion on the Cape.

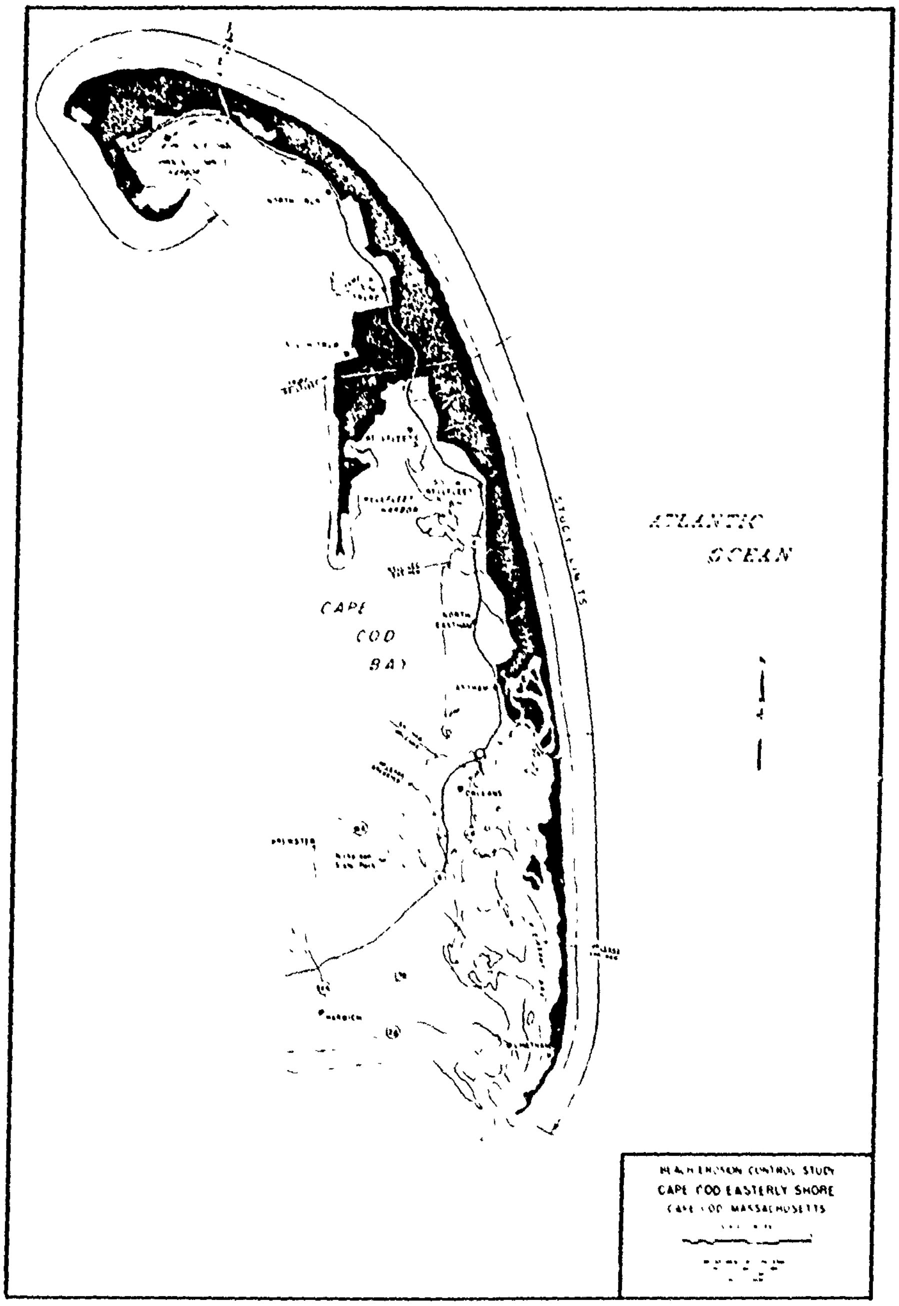

Figure 1-F1. Cape Cod National Seashore boundaries

Table 1-F1. Cape Cod National Seashore

TOWNSHIP	ACRES WITHIN SEASHORE BOUNDARY
Provincetown	7,950
Truro	11,800
Wellfleet	12,300
Eastham	4,800
Orleans	4,100
Chatham	3,650
Total	44,600[1]

[1] Of the total 44,600 acres in the National Seashore, 15,400 acres are formally not subject to acquisition according to the legislation which created the Seashore. These acres belong to the State (12,000 acres including tidelands), towns (2,100 acres), and private individuals with dwellings in place before September 1, 1959 (1,300 acres). The Seashore will eventually acquire all the remaining 29,900 acres within its boundary.

The inconsistency in some towns between land acreage in the town and within the boundary of the Seashore occurs because the Seashore covers tidal area (lands lying one-quarter mile from shoreline into ocean and bay), while the townships do not.

Source: Cape Cod Planning and Economic Development Commission

Table 1-F2. Year-Round and seasonal population and population density

	YEAR-ROUND POPULATION					SEASONAL POPULATION			
TOWNSHIP	1950 FEDERAL CENSUS	1970 FEDERAL CENSUS	1976 ESTIMATE	1970-76 PERCENT CHANGE	1950-76 PERCENT CHANGE	1976 ESTIMATE	YEAR-ROUND AS PERCENT OF SEASONAL POPULATION 1976	LAND AREA (square miles)	DENSITY PER SQUARE MILE 1976
Provincetown	3,275	2,911	4,019	+38.1	+ 5.9	16,995	23.6	10.27	391
Truro	661	1,234	1,274	+ 3.2	+ 92.7	11,834	10.8	21.90	58
Wellfleet	1,123	1,743	2,004	+15.0	+ 78.5	13,348	15.0	22.22	90
Eastham	860	2,043	3,118	+52.6	+262.6	16,774	18.6	15.84	197
Orleans	1,759	3,055	4,424	+44.8	+151.5	11,754	37.6	21.22	208
Chatham	2,457	4,554	6,118	+34.3	+149.0	19,874	30.8	24.47	250
Totals:									
Outer Cape	10,655	15,540	20,957	+34.9	+ 96.7	90,579	23.1	115.92	181
Barnstable County	46,805	96,656	128,849	+33.3	+175.3	389,724	33.1	437.96	294
Outer Cape as Percentage of Barnstable County		16.1	16.3			23.2		26.5	

Source: MacConnell et al (1974) and Cape Cod Planning and Economic Development Commission

Table 1-F3. Average employment and number of firms, 1975

TOWNSHIP	INDUSTRY							
	AGRICULTURE FORESTRY FISHERIES	CONSTRUCTION	MANUFACTURING	TRANSPORTATION COMMUNICATION UTILITIES	WHOLESALE AND RETAIL TRADE	FINANCE INSURANCE REAL ESTATE	SERVICES	TOTAL
PROVINCETOWN								
Average Employment	96	40	71	41	697	104	301	1,350
Number Firms	29	21	8	12	136	11	57	274
TRURO								
Average Employment	2	21	6	5	45	1	118	198
Number Firms	1	9	1	2	14	1	30	58
WELLFLEET								
Average Employment	1	35	1	1	197	12	64	311
Number Firms	1	14	1	2	45	3	19	85
EASTHAM								
Average Employment	4	88	35	-	168	14	90	399
Number Firms	2	33	2	-	23	7	16	83
ORLEANS								
Average Employment	16	94	97	136	871	65	230	1,509
Number Firms	6	41	7	9	81	17	56	217
CHATHAM								
Average Employment	44	149	25	26	637	59	363	1,303
Number Firms	11	50	5	12	103	18	46	245
TOTALS:								
OUTER CAPE								
Average Employment	163	427	235	209	2,615	255	1,166	5,070
Number Firms	50	168	24	37	402	57	224	962
BARNSTABLE COUNTY								
Average Employment	485	1,966	1,830	2,631	11,618	1,840	9,460	29,830
Number Firms	144	747	133	177	1,537	57	1,110	3,905

Source: Massachusetts Division of Employment Security (compiled by Cape Cod Planning and Economic Development Commission)

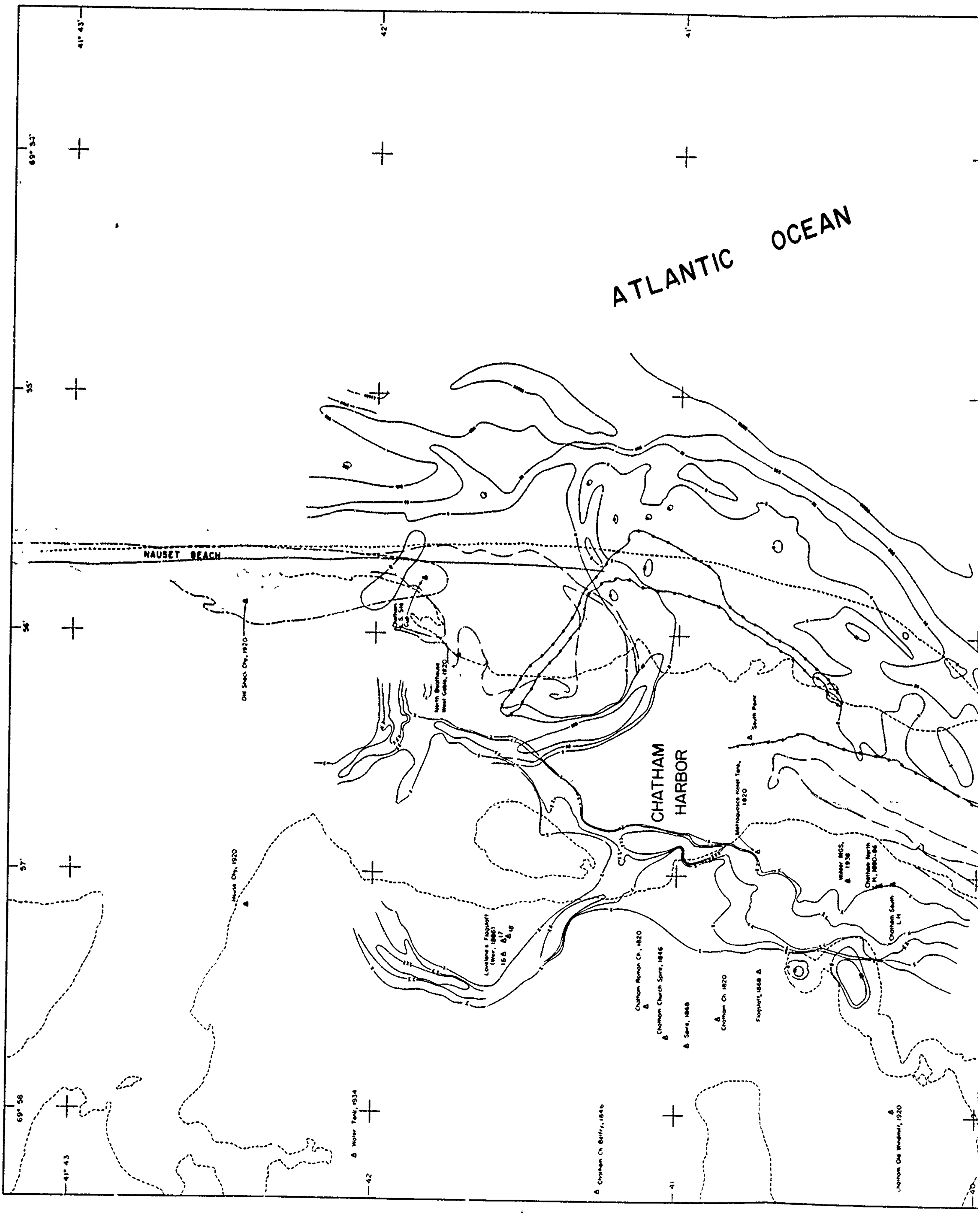
ATLANTIC OCEAN
NAUSET BEACH
CHATHAM
HARBOR
41° 43'
42'
41'
69° 54'
55'
56'
57'
69° 58'
House Chy, 1920
Chatham Roman Ch., 1820
Chatham Church Spire, 1846
Spire, 1868
Chatham Ch. 1820
Flagstaff 1868
Water Tank, 1934
Chatham Ch Belfry, 1846
Chatham South L.H.

Table 1-F5. Land use, 1951

TOWNSHIP	FOREST LAND (acres)	AGRICULTURAL OR OPEN (acres)	WETLANDS (acres)	URBAN: RESIDENTIAL (acres)	URBAN: OTHER (acres)	TOTAL (acres)
Provincetown	2,320	2,930	900	255	171	6,576
Truro	9,052	3,177	1,548	195	41	14,013
Wellfleet	8,094	2,404	2,688	317	81	13,584
Eastham	4,796	2,623	2,384	335	2	10,140
Orleans	5,276	2,065	5,403	783	56	13,583
Chatham	4,108	3,973	6,143	1,332	104	15,660
Totals:						
Outer Cape	33,646	17,172	19,066	3,217	455	73,556
Barnstable County	173,895	42,257	45,065	15,190	3,900	280,307

Source: MacConnell et al (1974)

Table 1-F5. Land use, 1951

TOWNSHIP	FOREST LAND (acres)	AGRICULTURAL OR OPEN (acres)	WETLANDS (acres)	URBAN: RESIDENTIAL (acres)	URBAN: OTHER (acres)	TOTAL (acres)
Provincetown	2,320	2,930	900	255	171	6,576
Truro	9,052	3,177	1,548	195	41	14,013
Wellfleet	8,094	2,404	2,688	317	81	13,584
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Orleans	5,276	2,065	5,403	783	56	13,583
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Totals:						
Outer Cape	33,646	17,172	19,066	3,217	455	73,556
Barnstable County	173,895	42,257	45,065	15,190	3,900	280,307

Source: MacConnell et al (1974)

Table 1-F7. Year-round population projections

TOWNSHIP	1975[1]	1995[2]	2027[3]
Provincetown	3,900	4,600	4,900
Truro	1,400	2,100	5,000
Wellfleet	2,000	2,800	7,800
Eastham	3,100	5,400	11,000
Orleans	4,400	7,200	11,000
Chatham	6,000	8,500	10,000[4]
Totals:			
Outer Cape	20,800	30,600	49,700
Barnstable County	128,000	187,000	330,000

[1]Current estimates.

[2]Herr projection with few modifications.

[3]Saturation level based on Herr report or continuation of present trend.

[4]The Metcalf and Eddy report estimated a winter saturation level of 29,280 with present zoning, 26,640 with modified zoning. The "most probable" development would yield a year-round population of 14,000 in 2020.

Table 1-F7. Year-round population projections

TOWNSHIP	1975[1]	1995[2]	2027[3]
Provincetown	3,900	4,600	4,900
Truro	1,400	2,100	5,000
Wellfleet	2,000	2,800	7,800
Eastham	3,100	5,400	11,000
Orleans	4,400	7,200	11,000
Chatham	6,000	8,500	10,000[4]
Totals:			
Outer Cape	20,800	30,600	49,700
Barnstable County	128,000	187,000	330,000

[1]Current estimates.

[2]Herr projection with few modifications.

[3]Saturation level based on Herr report or continuation of present trend.

[4]The Metcalf and Eddy report estimated a winter saturation level of 29,280 with present zoning, 26,640 with modified zoning. The "most probable" development would yield a year-round population of 14,000 in 2020.

Table 1-F8. Summer population projections

TOWNSHIP	1975[1]	1995[2]	2027[3]
Provincetown	16,900	20,000	21,400
Truro	11,900	17,000	21,600
Wellfleet	13,400	19,000	20,000
Eastham	16,400	23,000	28,000
Orleans	11,500	18,000	25,000
Chatham	19,500	26,000	27,300[3]
Totals:			
Outer Cape	89,600	123,000	143,300
Barnstable County	380,000	570,000	745,000

[1]Herr estimates and projections with few modifications.

[2]Saturation level, based on Herr report or continuation of present trend.

[3]The Metcalf and Eddy report estimated a summer saturation level of 58,700 with present zoning, 54,900 with modified zoning. The "most probable" development pattern would project a summer total population of 39,300 in 2020.

Table 1-F9. Land saturation[1]

TOWNSHIP	AVAILABLE LAND 1975 (acres)	POTENTIAL REMAINING DEVELOPMENT UNITS	ASSUMED ANNUAL CONSTRUCTION	SATURATION DATE
Provincetown[2]	-	-	-	-
Truro	2,800	2,800	40	2047
Wellfleet	2,200	3,400	70	2024
Eastham	3,200	4,900	120	2016
Orleans	4,000	3,100	130	1999
Chatham	1,900	2,800	130	1997
Totals:				
Outer Cape	14,100	17,000	490	-
Barnstable County	93,600	101,000	3,900	2001

[1]Assuming low estimate of dwellings at saturation (Herr report) and assuming continuation of 1970-74 residential construction rates.

[2]Now effectively at saturation.

Source: Philip B. Herr and Associates

Table 1-F10. Land use projection, 1995

TOWNSHIP	TOTAL[1] (EX. WATER) (acres)	NONRESERVED,[2] WET, SAND (acres)	RESERVED[3] OPEN (acres)	DEVELOPED[4] (acres)	RESIDUAL[5] (acres)
Provincetown	6,400	600	5,150	630	20
Truro	13,600	500	9,000	2,300	1,800
Wellfleet	13,300	900	8,500	2,700	1,200
Eastham	9,200	700	3,200	3,500	1,800
Orleans	9,000	500	1,600	5,200	1,700
Chatham	10,200	600	4,400	4,800	400
Totals:					
Outer Cape	61,700	3,800	31,850	19,130	6,920
Barnstable County	253,000	35,000	60,000	116,000	42,000

Source: Herr Report, specifically:

[1]MacConnell et al, 1974.

[2]"Cape Cod 1980," Blair Associates, 1963.

[3]CCPEDC Open Space and Recreation Maps, 1975, and Philip B. Herr and Associates estimates.

[4]Herr estimate.

[5]Vacant, buildings.

Table 1-F11. Total visits to Cape Cod National Seashore

YEAR	TOTAL VISITS
1964	1,849,875
1965	2,306,133
1966	2,830,288
1967	3,040,509
1968	3,475,842
1969	4,031,258
1970	3,987,001
1971	4,188,300
1972	4,972,281
1973	4,741,975
1974	4,359,393
1975	5,222,895
1976	5,018,707

Source: National Park Service

Table 1-F12. Present use of Cape Cod National Seashore

CLASS	TYPE	ACRES
1	High-density recreation areas	0
2	General outdoor recreation	4,400
3	Natural environment areas	21,800
4	Outstanding natural features	450
5	Primitive areas	770
6	Historic and cultural sites	240
-	Unclassified - U.S. Route 6	40
	Total	27,700

Source: Master Plan, Cape Cod National Seashore, 1974.

Table 1-F13. Recreational supply and demand on Cape Cod

ACTIVITY	1975 SUPPLY (Activity Days)[1]	1975 DEMAND (Activity Days)	DEMAND CURRENTLY SATISFIED (%)	NEEDS (Demands Not Satisfied) (Activity Days)
Boating	1,800,000	2,800,000	64	1,000,000
Swimming	29,700,000	9,200,000	323	0
Camping	500,000	1,400,000	36	900,000
Salt Water Fishing	-[2]	1,800,000	-	-

[1]Activity days or user days are defined as the use of a facility for any period of time during a single day. Supply "activity days" are based on nationwide surveys that identify preferences for type and amount of recreation based on social and economic characteristics of the population. These figures have been modified by additional surveys designed specifically for Massachusetts. Supply figures are based on the actual facilities and their ability to physically accommodate users. Although the figures are as accurate as possible, they should not be construed as absolute; their real value lies in the relative comparison of regions and activities.

[2]Impossible to estimate, but presumed at least as high as boating.

Source: Massachusetts Coastal Zone Management Program, 1977.

Table 1-F14. Existing recreational fleet

TOWNSHIP	SLIPS	MOORINGS	TOTAL
Provincetown[1]	150	300	450
Truro[2]	-	55	55
Wellfleet[2]	150	115	265
Eastham[2]	40	60	100
Orleans[2]	260	120	380
Chatham[2]	155	940	1,095
Total	755	1,590	2,345

[1]Source: Massachusetts Coastal Zone Management Program, 1977.

[2]Source: Estimates for 1972 from Southeastern New England Study, 1975.

Table 1-F15. Potential for recreational boating facilities[1]

TOWNSHIP	POTENTIAL ADDITIONAL SLIPS	POTENTIAL ADDITIONAL MOORINGS	POTENTIAL ADDITIONAL SPACES
Provincetown	-	70	70
Truro	-	-	-
Wellfleet	120	-	120
Eastham	50	100	150
Orleans	200	820	1,020
Chatham	200	520	720
Total	570	1,510	2,080

[1]These are preliminary estimates and should not be construed as justification for marina development or expansion. Further study either by towns or by the proposed statewide boating advisory committee is needed to determine capacities for new facilities.

Source: Southeastern New England Study, 1975.

Table 1-F16. Shellfish permits, 1976

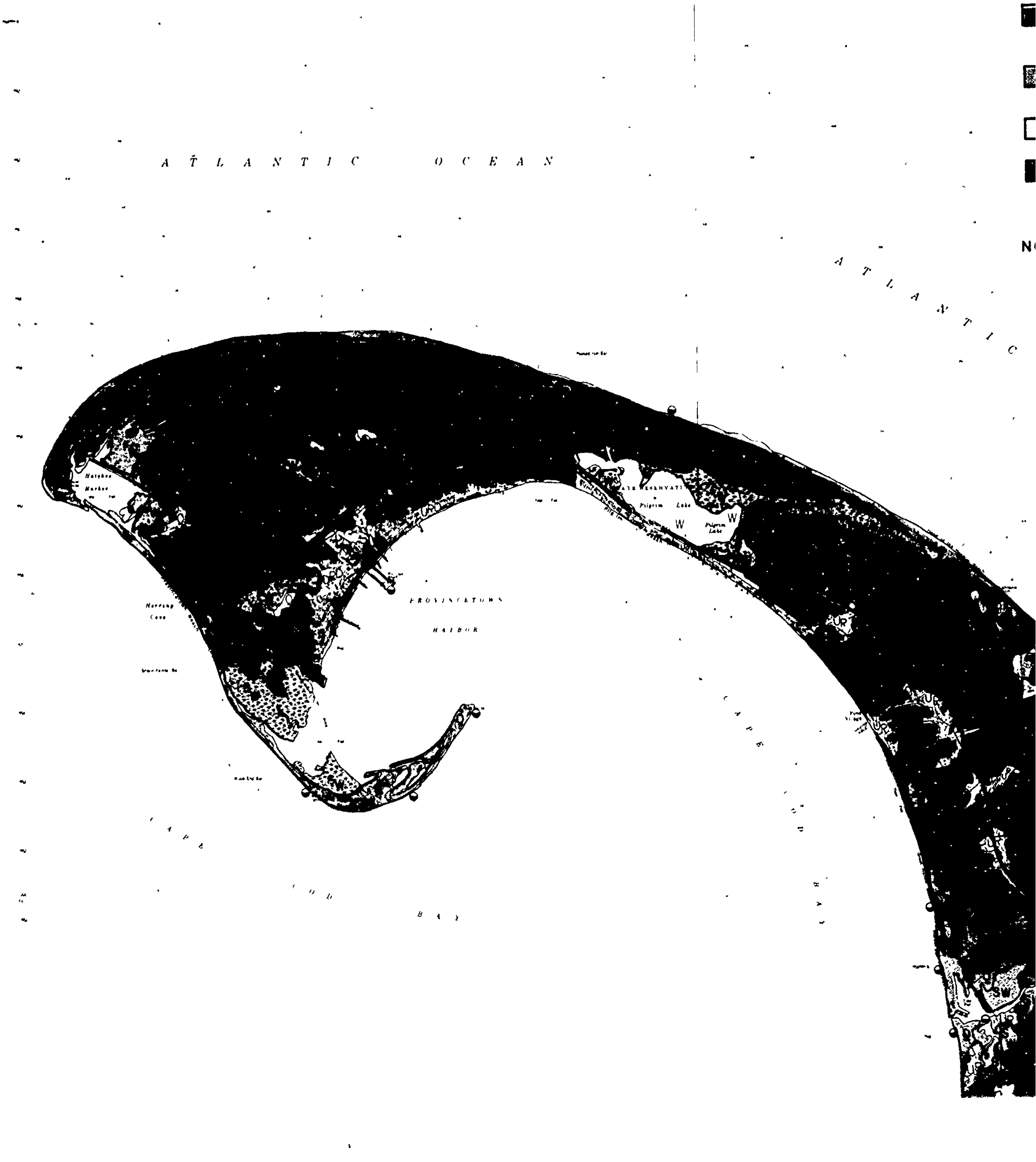
TOWNSHIP	RESIDENT FAMILY	NON-RESIDENT	COMMERCIAL	COMMERCIAL SCALLOP	FREE	TOTAL
Provincetown	363	1	-	-	-	364
Truro	517	94	-	-	-	611
Wellfleet	676	99	258	-	-	1,033
Eastham	1,124	852	200	-	-	2,176
Orleans	631	116	140	138	177	1,202
Chatham	1,522	377	162	144	146	2,351
Total	4,833	1,539	760	282	323	7,737

Source: Cape Cod Planning and Economic Development Commission.

Table 1-F17. Average employment in wholesale and retail trades and services, 1975

TOWNSHIP	EMPLOYMENT IN WHOLESALE AND RETAIL TRADE	EMPLOYMENT IN SERVICES	TOTAL EMPLOYMENT	PERCENT OF TOTAL IN WHOLESALE, RETAIL, AND SERVICES
Provincetown	697	301	1,350	73.9
Truro	45	118	198	82.3
Wellfleet	197	64	311	83.9
Eastham	168	90	399	64.7
Orleans	871	230	1,509	73.0
Chatham	637	363	1,303	76.7
Total	2,615	1,166	5,070	74.6

Source: Massachusetts Division of Employment Security (compiled by Cape Cod Planning and Economic Development Commission).


ATLANTIC OCEAN
PROVINCETOWN HARBOR
CAPE COD BAY
Pilgrim Lake

CAPE COD EASTERLY SHORES

Color Code for Land-Use Maps

- All forest types, agricultural and open types (including golf courses and high dunes).
- All wetland types and beaches immediately adjacent to water, including beach-recreation areas.
- All residential types.
- All urban commercial, industrial, and transportation types (including airports, major highway routes).

Ponds and water have been left white.

NOTE:

For details see "Massachusetts map down 1971 Land use and vegetative cover mapping". University of Massachusetts, Department of Forestry and Wildlife Management.

NOT TO SCALE

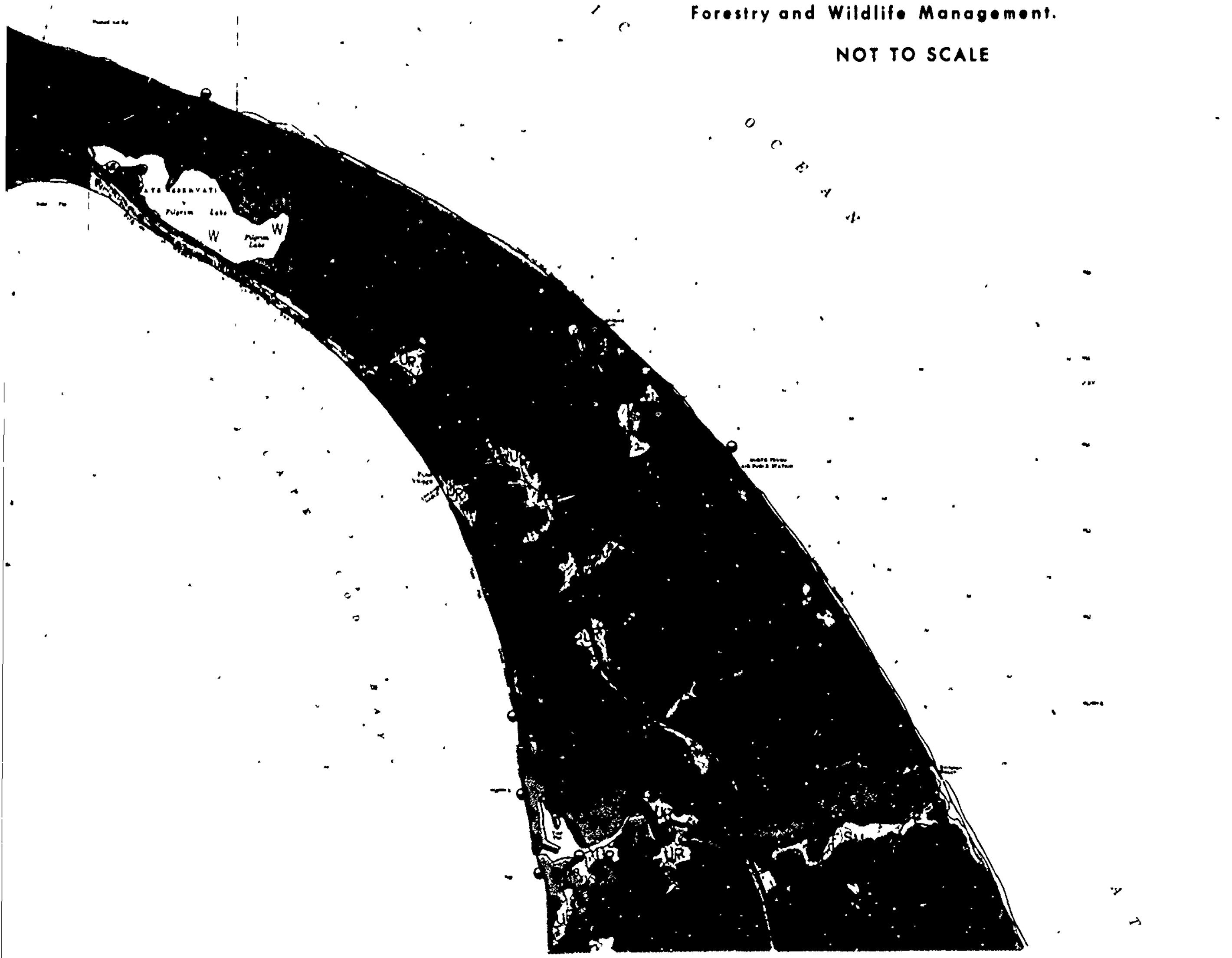


PLATE F-1

CAPE COD EASTERLY SHORES

Color Code for Land-Use Maps

- All forest types, agricultural and open types (including golf courses and high dunes).
- All wetland types and beaches immediatly adjacent to water, including beach-recreation areas.
- All residential types.
- All urban commercial, industrial, and transportation types (including airports, major highway routes).

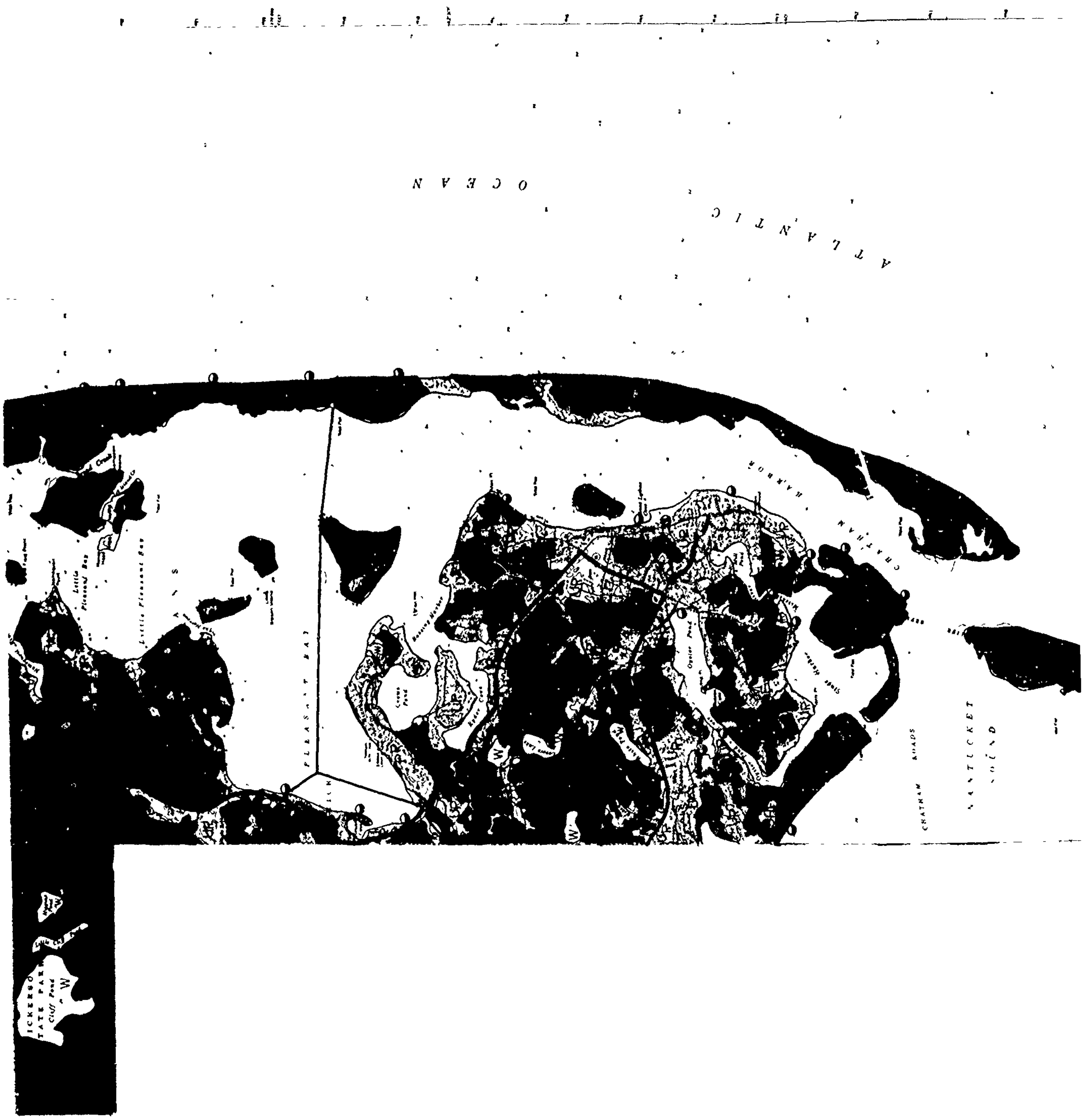
Ponds and water have been left white.

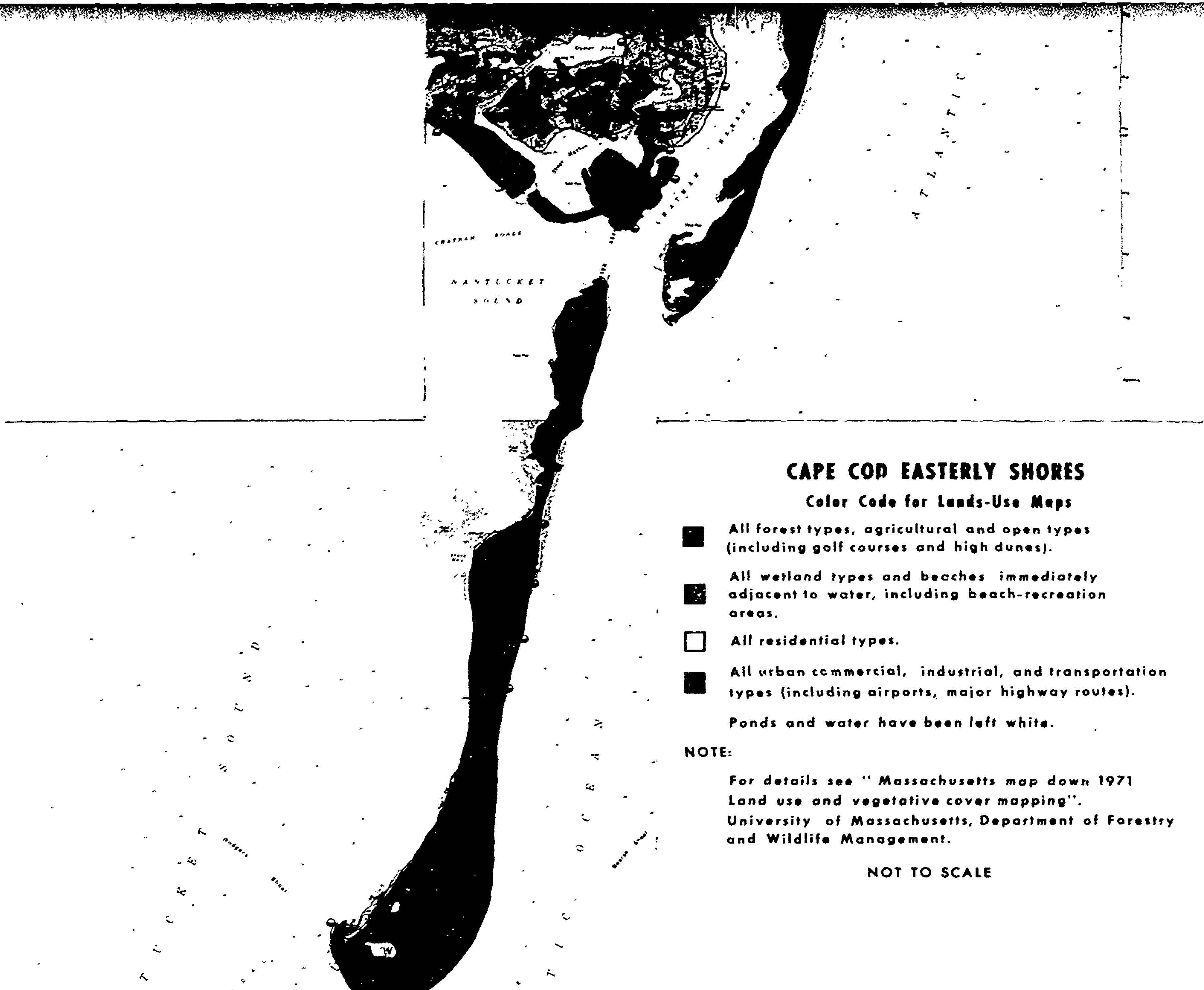
NOTE:

For details see "Massachusetts map down 1971 Land use and vegetative cover mapping". University of Massachusetts, Department of Forestry and Wildlife Management.

NOT TO SCALE

PLATE F-2


ATLANTIC
OCEAN
PLEASANT BAY
Little Pleasant Bay
CHATHAM HARBOR
CHATHAM ROADS
NANTUCKET SOUND



CAPE COD EASTERLY SHORES

Color Code for Lands-Use Maps

- All forest types, agricultural and open types (including golf courses and high dunes).
- All wetland types and beaches immediately adjacent to water, including beach-recreation areas.
- All residential types.
- All urban commercial, industrial, and transportation types (including airports, major highway routes).

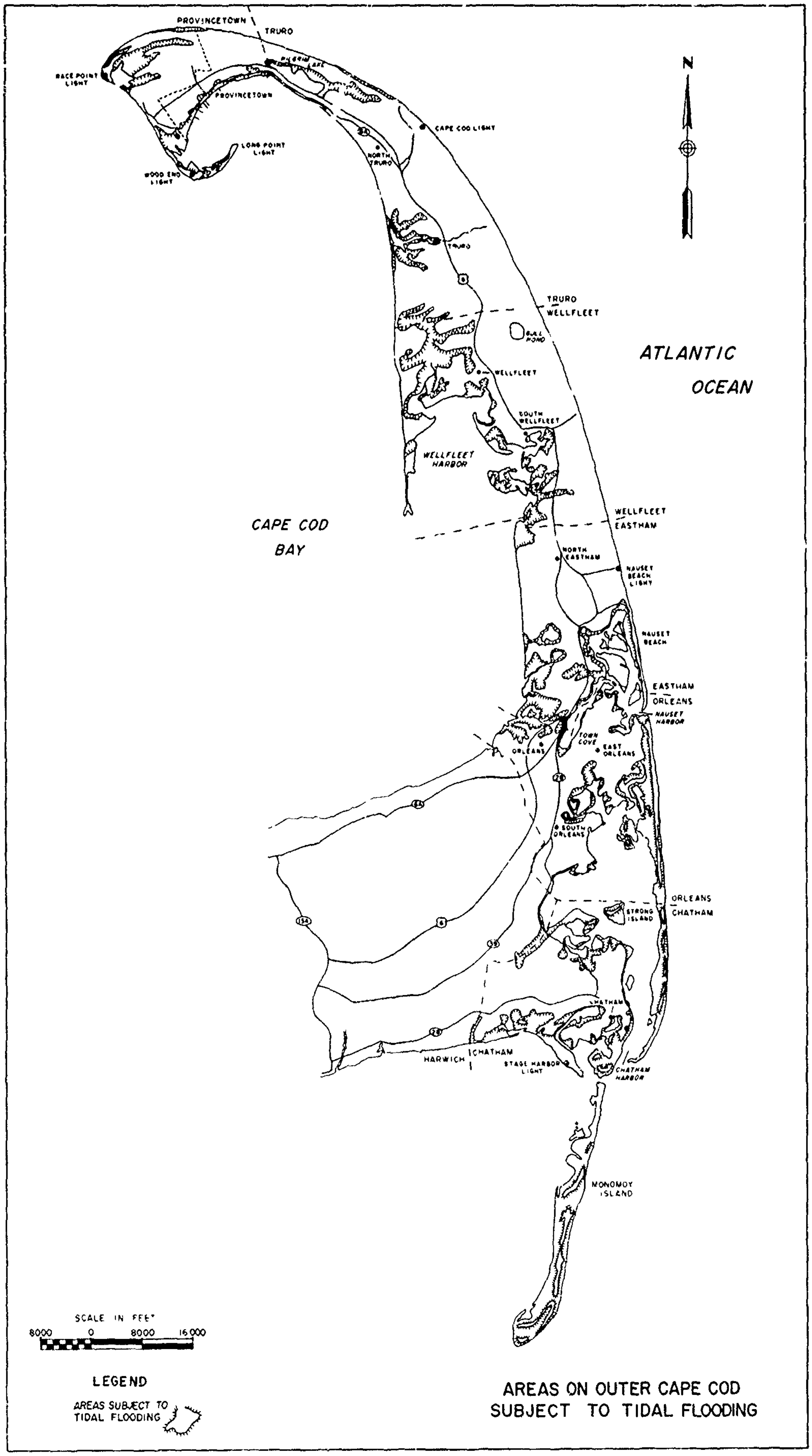
Ponds and water have been left white.

NOTE:

For details see " Massachusetts map down 1971 Land use and vegetative cover mapping". University of Massachusetts, Department of Forestry and Wildlife Management.

NOT TO SCALE

PLATE F-3



AREAS ON OUTER CAPE COD SUBJECT TO TIDAL FLOODING

PLATE F4

SECTION G

DISCRIPTION OF BEACHES EROSION

DESCRIPTION OF BEACHES

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PLATES

DISCRIPTION OF BEACHES

INTRODUCTION

From the end of Long Point in Provincetown to the tip of Nauset Beach in Chatham, the outer perimeter of Cape Cod is one long sandy beach with only two interruptions. Some parts of the beach are specifically named and are accessible by the public. Other portions of the beach are less precisely named and are reached with greater difficulty. Plate G-1, located at the end of this section, identifies the various beaches of Cape Cod.

BEACHES OF OUTER CAPE COD

Location - Long Point to the tip of Nauset Beach.

Shore Length - Total length of outer shore, 47 miles; 1.6 miles, Long Point to Wood End Coast Guard Station; 4.3 miles, Wood End Coast Guard Station to Race Point Lighthouse; 41.1 miles, Race Point Lighthouse to the tip of Nauset Beach.

Ownership - U.S. Government, towns, and private individuals, all under jurisdiction of Cape Cod National Seashore, National Park Service.

Beach Use - Swimming on all beaches, with the more remote beaches limited to campers and fishermen with beach buggies.

Public Facilities - Variable from none to parking lots accompanied by bathhouses and refreshment stands. In some areas, access to the beach is provided by wooden boardwalks and stairs.

Beach Width - Varies with location and season. Summer beaches range from 50 to 250 feet; winter beaches may range from 0 to 100 feet with high tides and storm waves reaching the base of the dunes or scarp.

Composition of Shore - Generally course- to fine-grained sand backed by dunes or scarps ranging from 10 feet high on the north spit at the entrance to Nauset Harbor to 158 feet high behind Longnook Beach.

A study of the grain size of outer Cape Cod beach sands (Figure 1-G1) indicated a trend of decreasing grain size from Herring Cove Beach to the tip of Nauset Beach (Fisher, 1972). These results are confirmed by Zimmerman (1963)

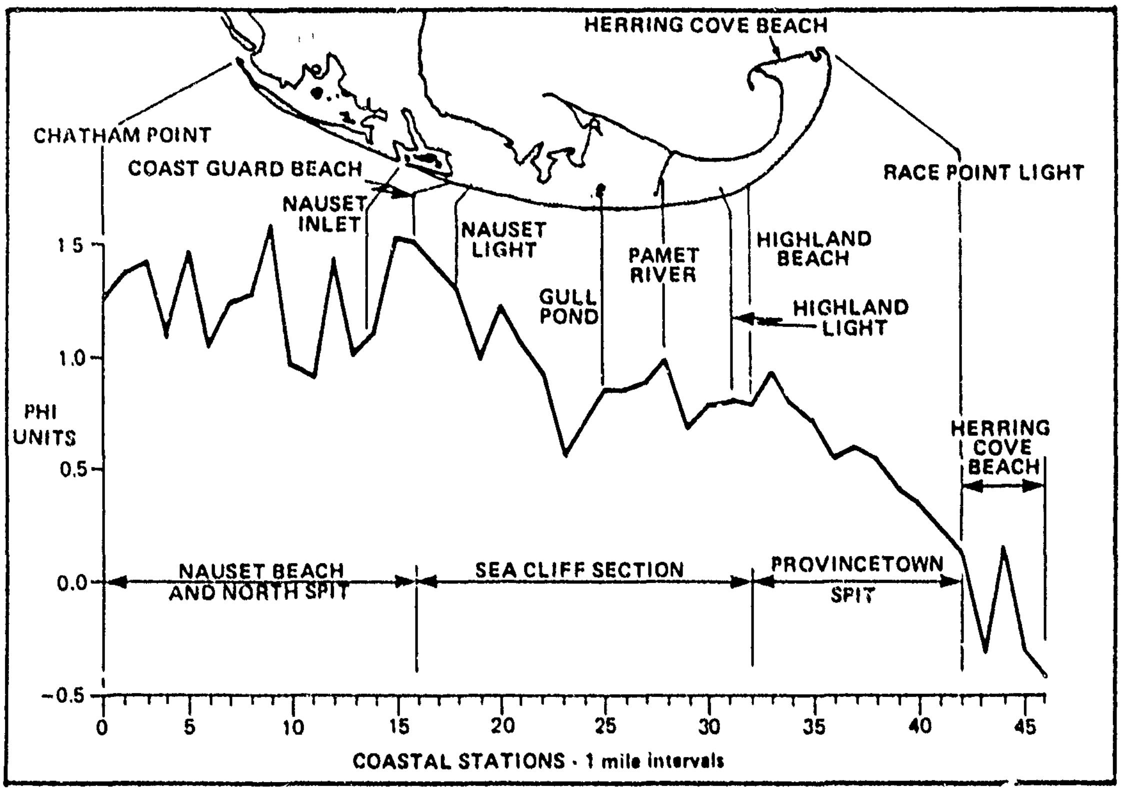


Figure 1-G1. Median grain size of foreshore beach sands, outer Cape Cod beaches (after Fisher, 1972)

for the north spit at the inlet to Nauset Harbor (Figure 1-G2). In both studies, grain size varied from sample to sample, but the trend indicated decreasing grain size from north to south.

Protective Structures - None, except for several groins on Herring Cove Beach. Sand fences, Christmas trees, and grass plantings have been utilized for sand retention in several areas at various times. The projects have been successful but have suffered during severe storms. The sand accumulations did lessen the storm damage in significant areas - Ballston Beach, Nauset Beach 4, and Nauset Beach 7.

Shore Structures - Structures along the Cape Cod shoreline include functioning and necessary lighthouse radio beacons and communications towers, permanent and seasonal homes, parking lots, wooden stairways, and various other small buildings. Some are in immediate danger of being undermined by erosion; others appear to have a longer reprieve.

Character of Development - Most of Cape Cod's outer shoreline is in an unspoiled state. Building along the dune edge is relatively sparse. Some conveniences have been provided for beach users, but generally the public gains access at specific limited points. Much of Cape Cod's more remote shoreline is accessible by boat and beach buggy.

LONG POINT

Location - End of hook that makes up Provincetown.

Shore Length - Approximately 1.1 miles.

Ownership - Federal; United States Coast Guard.

Beach Use - Access is by boat or by beach buggy.

Public Facilities - None.

Beach Width - Spit is approximately 500 feet wide.

Composition of Shore - Low-lying sand spit with dunes barely reaching several feet above sea level. There are no trees, but a scattering of brush is sufficient to hold the sand. Although the spit is frequently overtopped under storm conditions, it is protected from the open ocean by the rest of Cape Cod and is a relatively stable area in terms of erosion and accretion. Continual minor changes counteract each other leaving Long Point with a relatively stable appearance.

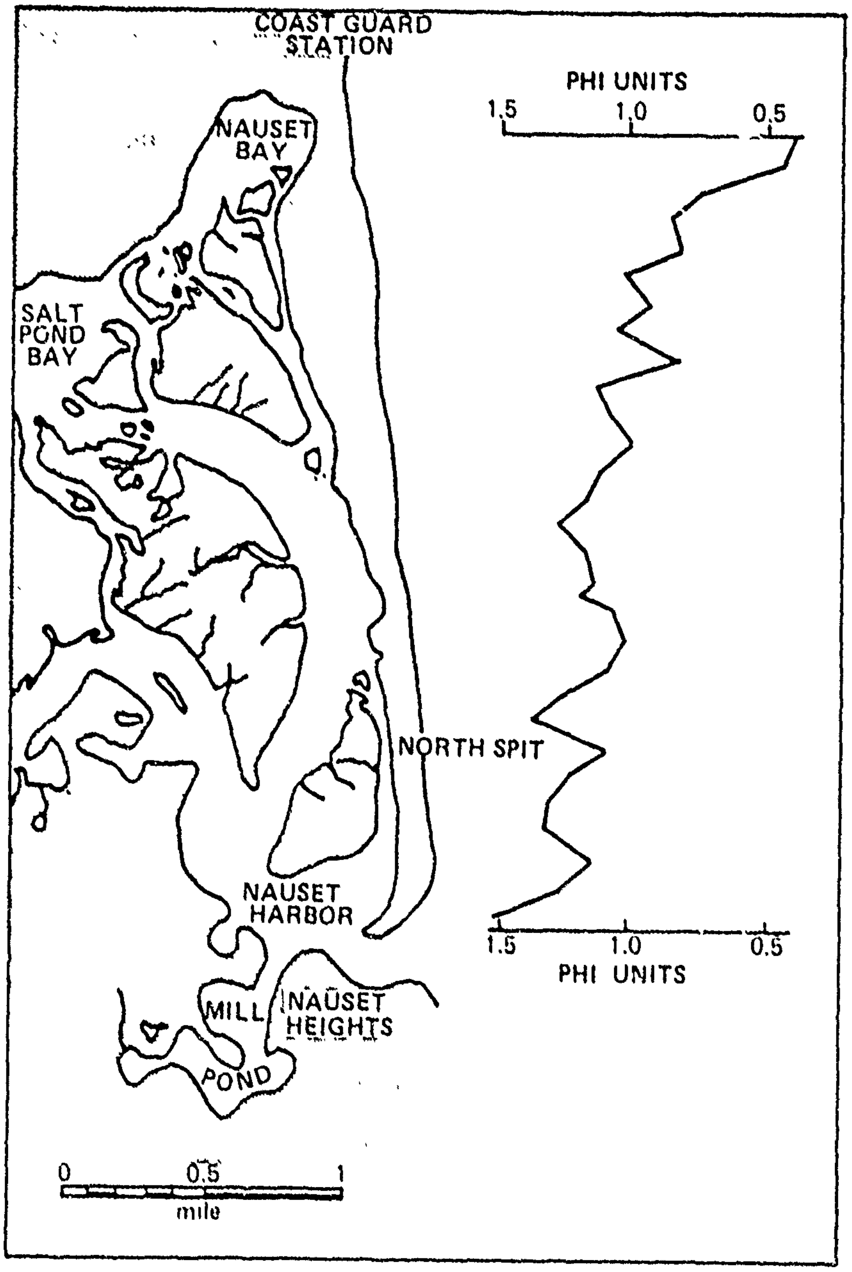


Figure 1-G2. Mean grain size of foreshore beach sands, north spit, Nauset Beach (after Zimmerman, 1963, in Fisher, 1972)

Protective Structures - None.

Shore Structures - Long Point Lighthouse on extreme end of hook; light is 36 feet above sea level. First illuminated in 1827, the light is still in operation.

Character of Development - No development.

WOOD END

Location - 1.5 miles due south of Telegraph Hill, Provincetown, on the sandy spit extending to Long Point.

Shore Length - Approximately 0.8 miles.

Ownership - Federal; United States Coast Guard.

Beach Use - Access is by boat or by beach buggy.

Public Facilities - None.

Beach Width - In April 1978, the beach was widest at the eastern end (almost 150 feet) and narrowest (about 40 feet) where the breach occurred at the western end.

Composition of Shore - Low-lying sand spit with dunes reaching a maximum elevation of approximately 12 feet above mean sea level.

Protective Structures - None. Although the area is naturally sheltered from most storms, overtopping of the spit is not uncommon.

Shore Structures - Wood End Lighthouse built in 1872 and Wood End Coast Guard Station, located 1/8 mile east of Wood End Light, built in 1896 and manned in 1897.

Character of Development - None except Coast Guard Station.

HERRING COVE BEACH

Location - Between the marshes and Hatches Harbor (Figure 1-G3).

Shore Length - Shoreline, 4.3 miles; Herring Cove Beach, 1 mile.

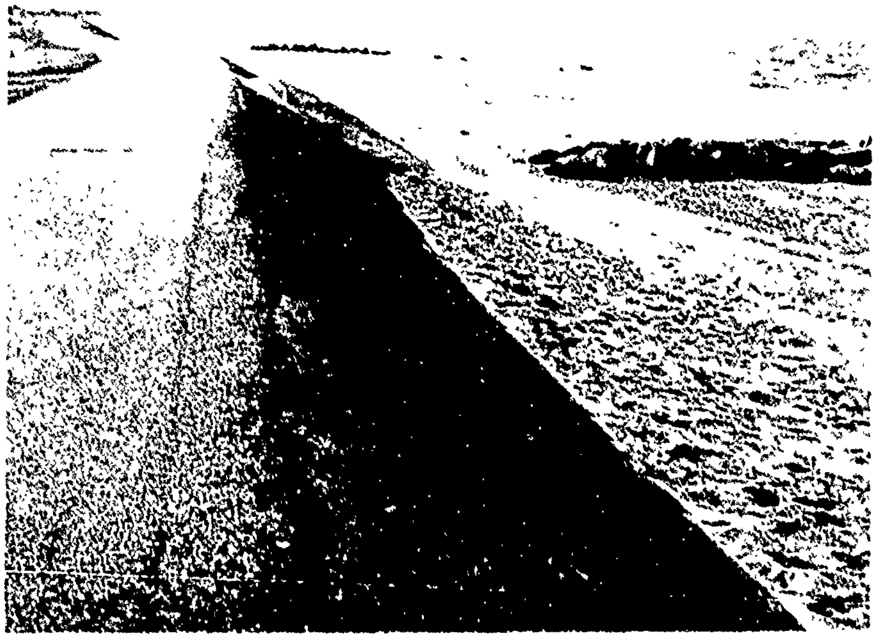


Figure 1-G3. Herring Cove Beach

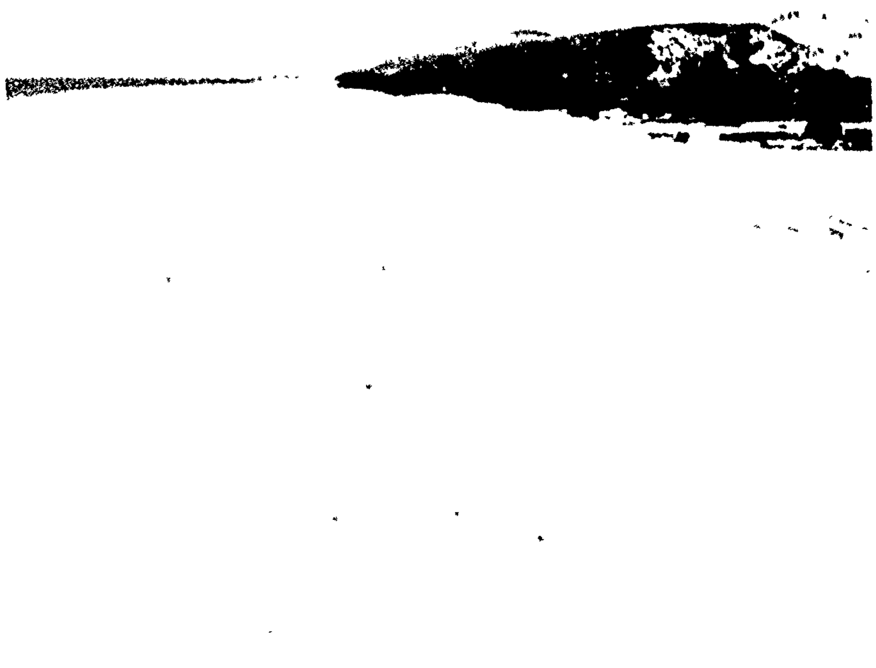


Figure 1-G4. Herring Cove Beach showing crumbling seawall

Figure 1-G5. Race Point Beach

Figure 1-G5. Race Point Beach

Composition of Shore - Coarse-grained sand. A wide, low-lying beach backed by 10- to 15-foot high, grass-covered dunes. In the area of Race Point, large quantities of sand are deposited annually, but the shoreline changes only slightly because the sand deposited on the beach is later blown inland. Peaked Hill Bar, a fairly permanent longshore bar, is about 2000 feet offshore from Race Point Beach. The bar begins offshore from Highland Beach and parallels the shore until it makes a sharp turn to the south at Race Point. At this point Peaked Hill Bar also turns but gradually merges into the shoreline (Fisher, 1972). The coast at Race Point is very treacherous due to the high velocity of tidal currents.

Protective Structures - None.

Shore Structures - Race Point Lighthouse at the western-most tip of Provincetown was originally constructed in 1816. The lighthouse is owned and operated by the U.S. Coast Guard and is currently unmanned.

Race Point Coast Guard Station is located approximately 1/4 mile north of Provincetown Airport on the northernmost part of Cape Cod. A large parking area and public restrooms are adjacent to the station.

Character of Development - The land surrounding Race Point is desolate and unoccupied with views of open ocean and barren dunes as far as the eye can see. Race Point Coast Guard Station adjoins Provincetown Airport.

PROVINCETOWN

Location - Between the eastern boundary of Province Land State Reservation and the western boundary of Pilgrim Heights Area (Figures 1-G6 and 1-G7).

Shore Length - 2.0 miles.

Ownership - National Park Service.

Beach Use - Swimming and beach buggies.

Public Facilities - None.

Beach Width - 100 to 200 feet.

Composition of Shore - Coarse sandy beach backed by 20- to 30-foot high, grass-covered, sandy dunes.

Protective Structures - None.

Shore Structures - Occasional seasonal cottages at the edge of the dunes.

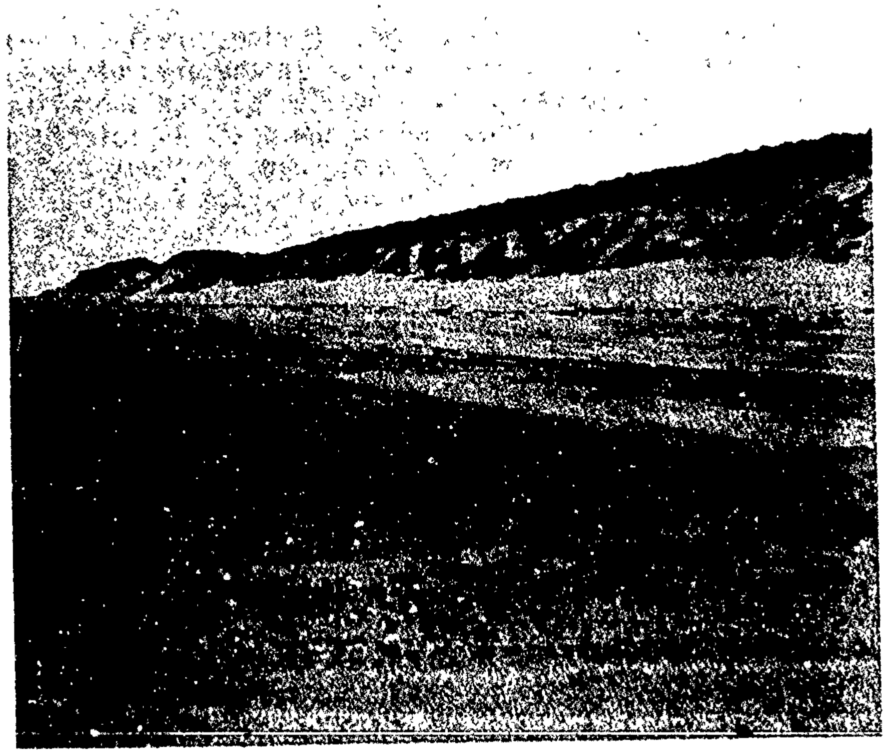


Figure 1-G6. Provincetown Beach

Figure 1-G7. Provincetown Beach showing dune erosion

Character of Development - This remote beach is reached by a dirt road nearly 1/2 mile inland from the beach.

HEAD OF THE MEADOW BEACH

Location - Between the western boundary of Pilgrim Heights Area and Highland Beach (Figures 1-G8 and 1-G9).

Shore Length - 4.7 miles.

Ownership - National Park Service.

Beach Use - Swimming.

Public Facilities - Two parking areas, one provided by the National Park Service, the other by the town of Truro.

Beach Width - 75 to 100 feet.

Composition of Shore - Fine-grained sand. Most of the beach is backed by a 20-foot high dune while the southern 1500 feet of the beach is backed by an 80-foot high sandy scarp; however, in two places northeast of Salt Meadow, the dune has been cut to within 10 feet of mean sea level. The dunes are covered by grass and other low salt-resistant plants, such as bayberry.

Protective Structures - None.

Shore Structures - There are no significant shore structures.

Character of Development - The area has been kept in its natural state with little development.

CAPE COD NATIONAL SEASHORE 1

Location - Between Head of the Meadow Beach and the northern boundary of the North Truro Air Force Station; includes Highland Beach (Figures 1-G10 and 1-G11).

Shore Length - 1.5 miles.

Figure 1-G8. Head of the Meadow Beach (looking northwest)

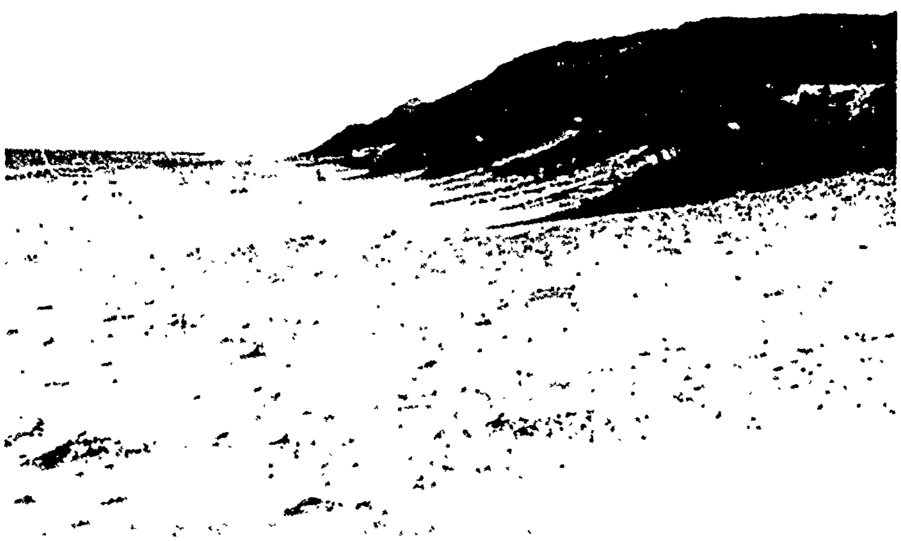


Figure 1-G9. Head of the Meadow (looking southeast) showing parking lot drainage pipe on right

Figure 1-G10. Highland Beach (looking southeast from Highland Light Coast Guard Station) at high tide, November 1977

Figure 1-G11. Highland Light Coast Guard Station showing gulley caused by surface runoff

Ownership - National Park Service.

Beach Use - Swimming.

Public Facilities - Limited parking; lifeguard protection for approximately 500 feet of Highland Beach.

Beach Width - Ranges from 0 to 25 feet in the south to 75 to 100 feet in the north; during the summer the beach is irregularly shaped, varying from 75 to 250 feet in width with considerable development of sand bars 50 to 200 feet offshore.

Composition of Shore - Medium-fine-grained sand. Beach extends to the base of 80- to 120-foot high scarps. At the base of the scarp, 30 to 70 feet of iron-stained, coarse sand to gravel containing pebbles and cobbles is overlain by 0 to 40 feet of gray clay and silty clay, which is then overlain by 15 to 20 feet of yellowish-gray, fine- to medium-grained sand (Fisher, 1972). This material erodes in an irregular manner as illustrated in Figure 1-G12.

Protective Structures - None.

Shore Structures - Highland or Cape Cod Light, originally constructed in 1797, is still an extremely important navigation aid. The light is manned and operated by the U.S. Coast Guard. A radio tower is located close to it.

Character of Development - The beach is the least developed of all the beaches within the National Seashore. The parking is limited and lifeguard protection is provided for only a small section of the beach.

Erosion problems in the area are aggravated by several factors. Access to the beach is not controlled, and as a result, beach users walk up and down the bank to the beach wherever it is convenient. In addition, surface drainage is routed by pipe to outfall over the face of the bank. Overland flow of runoff from the parking area, the access road, and the surrounding area also causes severe erosion as shown in Figure 1-G11.

LONGNOOK BEACH

Location - Between the northern boundary of the North Truro Air Force Station and the Green Hill radio towers (Air Force Station) (Figure 1-G13).

Shore Length - 1.5 miles.

Ownership - United States Air Force in front of the Air Force Station; town of Truro in the south.

Figure 1-G12. Erosion of bluff at Highland Light Coast Guard Station

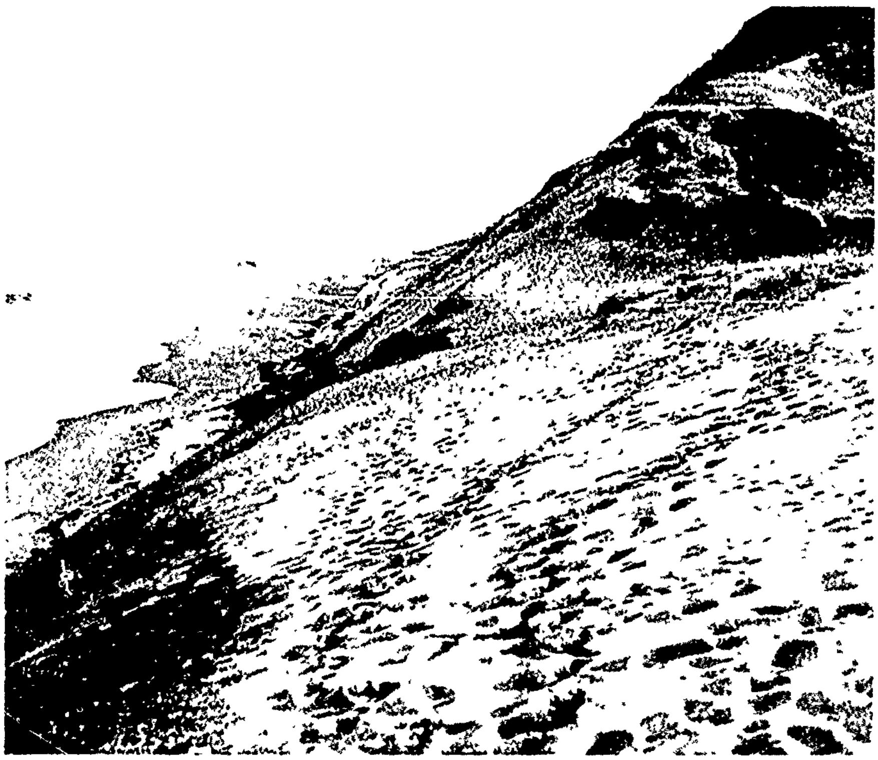


Figure 1-G13. Longnook Beach one hour after high tide, November 1977

Beach Use - Swimming.

Public Facilities - Small parking area.

Beach Width - 75 to 150 feet.

Composition of Shore - Fine-grain sand. Beach is backed by a scarp reaching a height of 158 feet at the radio tower site.

Protective Structures - None.

Shore Sructures - North Truro Air Force Station and radio towers on Green Hill. The road to the radio towers comes within 30 feet of the edge of the bluff and may well be threatened by continued erosion. There are a few seasonal homes between the North Truro Air Force Station and the radio towers; two of them are located on the edge of the bluff.

BALLSTON BEACH

Location - Between the Green Hill radio towers and Pamet Point (Figures 1-G14 and 1-G15).

Shore Length - 2.5 miles.

Ownership - Town of Truro.

Beach Use - Swimming.

Public Facilities - Parking area.

Beach Width - 75 to 150 feet.

Composition of Shore - Fine sand with gravel at wash line. The 100-foot high scarp behind the beach is deeply notched by the truncated valley of the Pamet River. A wide sandy beach of varying width and a narrow grass-covered dune less than 20 feet high are all that separate the Atlantic Ocean from the hanging valley of the Pamet River (see Figure 1-G16). The top of the scarp is also notched, producing additional erosion by blowouts.

Protective Structures - None. Grass has been planted on the dune east of Pamet River.

Shore Structure - None.

Character of Development - Several seasonal homes are located on and behind the dunes where North and South Pamet Roads approach the shore.

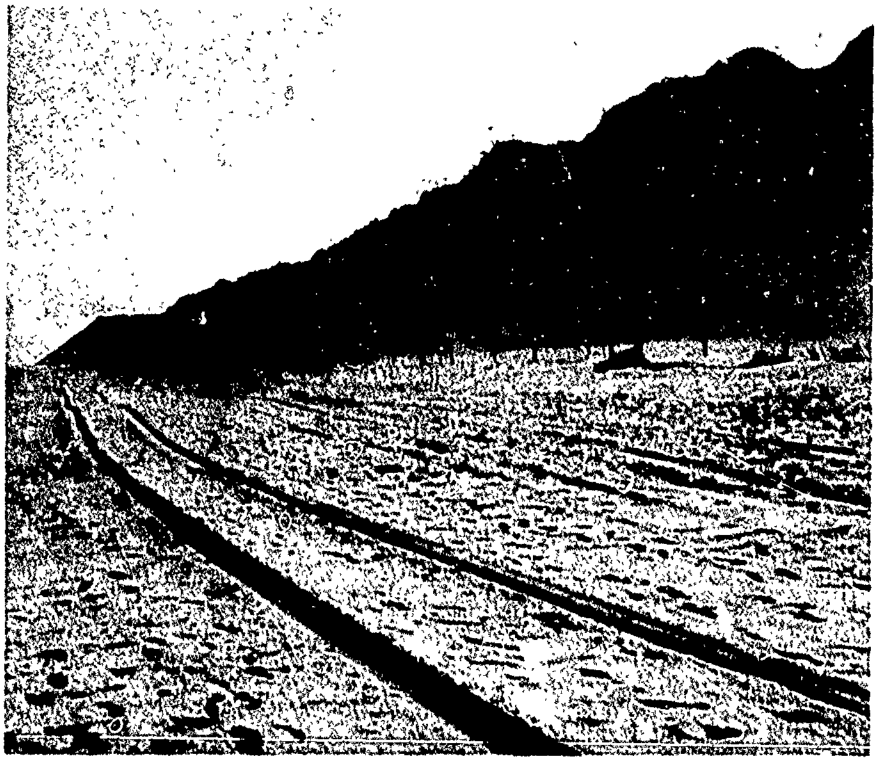


Figure 1-G14. Ballston Beach, April 1977

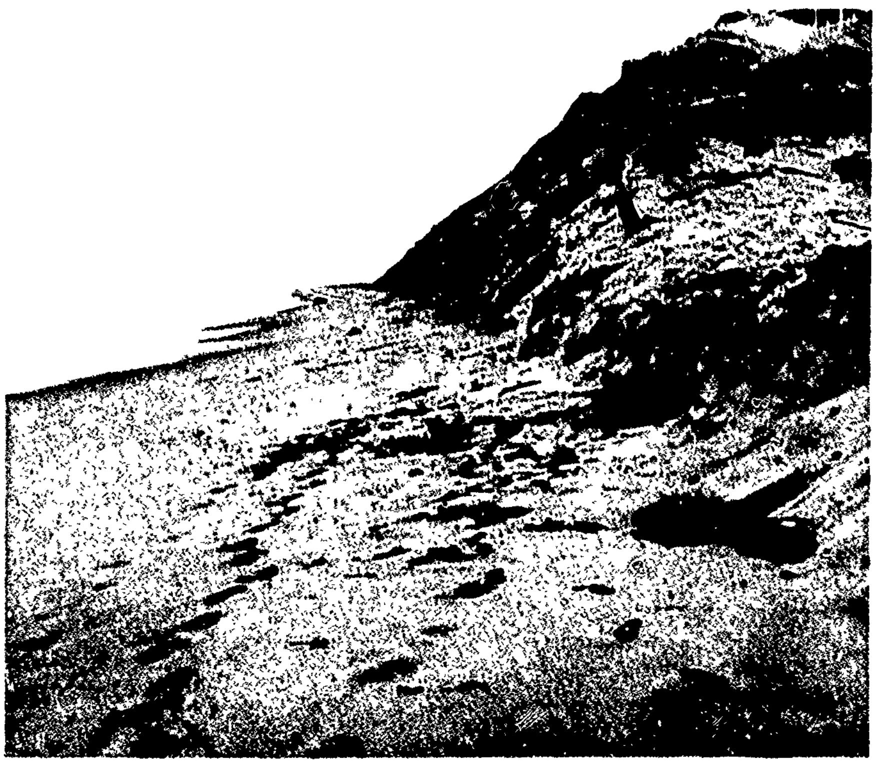


Figure 1-G15. Ballston Beach, November 1977

Figure 1-G16. Ballston Beach at narrowest point of Cape Cod; Atlantic Ocean on left, Pamet River on right

CAPE COD NATIONAL SEASHORE 2

Location - Between Pamet Point and the Truro-Wellfleet town line.

Shore Length - 1.7 miles.

Ownership - Town of Truro.

Beach Use - Swimming and beach buggies.

Public Facilities - Parking area.

Beach Width - 75 to 150 feet.

Composition of Shore - Fine-grained sand with gravel at wash line. The broad beach terminates against a high, 100-foot scarp that is interrupted by several pamets that provide access to the beach. (A pamet is a truncated, westward sloping stream valley that once drained runoff from the retreating glacier to the east of Cape Cod.)

Protective Structures - None.

Shore Structures - Several seasonal cottages on top of 50-foot dunes at south end of beach.

Character of Development - There are a few seasonal cottages at the southern end of the beach just north of the Truro-Wellfleet town line. The rest of the shore and dune area are undeveloped.

NEWCOMB HOLLOW BEACH AND CAHOON HOLLOW BEACH

Location - Between the Truro-Wellfleet town line and the parking area north of Wellfleet by the Sea (Figures 1-G17 and 1-G18).

Shore Length - 2.4 miles.

Ownership - Town of Wellfleet.

Beach Use - Swimming and beach buggies.

Public Facilities - Parking area.

Beach Width - 70 to 170 feet.

Figure 1-G17. Newcomb Hollow Beach and sand bar, April 1977

Figure 1-G18. Cahoon Hollow Beach, November 1977

Composition of Shore - Fine-grained sand in the north; coarse sand in the south. Both Newcomb Hollow Beach and Cahoon Hollow Beach are reached by "pamet sags" in the 100-foot scarp at the back of the beach. The scarp is composed of the younger Wellfleet deposit of glacio-fluvial origins as described under Marconi Beach.

Protective Structures - None.

Shore Structures - Approximately 30 seasonal cottages are located 300 to 800 feet from the edge of the scarp.

Character of Development - The beach, itself, is not developed, but there are nearly 50 houses west of Newcomb Hollow Beach and around Gull Pond. Ocean View Drive more or less parallels the shoreline, being closest to the shoreline at the parking area at the south end of Cahoon Hollow Beach.

LECOUNT HOLLOW BEACH

Location - Between the parking area north of Wellfleet by the Sea and the Marconi Station site (Figures 1-G19 and 1-G20).

Shore Length - 1.4 miles.

Ownership - Town of Wellfleet.

Beach Use - Swimming.

Public Facilities - Parking area.

Beach Width - 55 to 70 feet.

Composition of Shore - Fine-grained beach sand with gravel at wash line. The beach is backed by an 80- to 100-foot high, grass-covered, sandy scarp broached by a pamet sag, LeCount Hollow.

Protective Structures - None.

Shore Structures - There are numerous cottages and houses within 1000 feet of the shore line.

Character of Development - Wellfleet by the Sea and LeCount Hollow are substantial settlements including approximately 150 buildings, most of which are more than 100 feet from the edge of the dune.

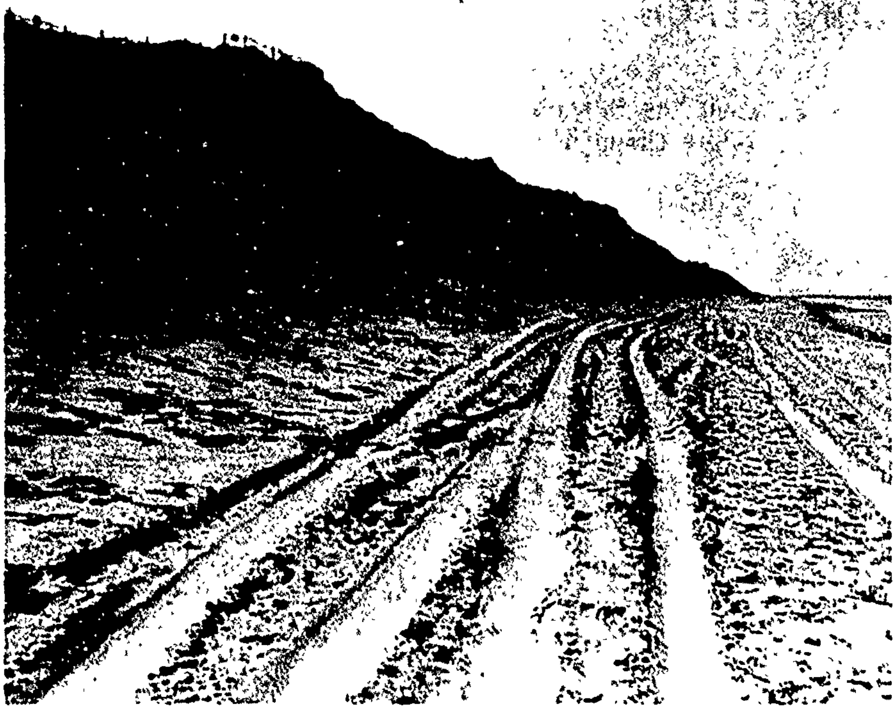


Figure 1-G19. LeCount Hollow Beach, April 1977

Figure 1-G20. LeCount Hollow Beach, November 1977

MARCONI BEACH

Location - Between the Marconi Station site and the Wellfleet-Eastham town line (Figures 1-G21 through 1-G23).

Shore Length - 2.4 miles.

Ownership - National Park Service.

Beach Use - Swimming.

Public Facilities - Bathhouse, parking for 528 cars, and boardwalks with stairs leading down the scarp to the beach.

Beach Width - 100 to 150 feet in summer; may be 20 feet or less during winter months.

Composition of Shore - Fine-grained beach sand with gravel at wash line. The beach is backed by a 40- to 50-foot high, grass-covered scarp which is readily eroded by wave action. One-third of the way down the cliff face is the contact between the younger and older Wellfleet outwash plain glacial deposits. The older (lower) unit is composed of fine to very coarse gravelly sand. However, within this unit are beds and lenses of pebble and cobble gravel, fine to very fine sand and clay-silt. Boulders, tens of feet in diameter, are common and some pebbles in the deposit are wind-polished. (The boulder-bearing formations have not been exposed on the beach scarp yet.) Planar bedding, crossbedding, and current ripples are evident. Reworked fossil material includes carbonized wood and shells of Pleistocene age, fossiliferous sandstone cobbles, silicified wood, and fish teeth (Fisher, 1972; Oldale, 1968). There is a dominance of quartzite stones.

The second, younger unit of the Wellfleet deposit is similar to the older Wellfleet deposit except that the boulders and clay-silt beds are not present. Planar and tabular bedding and crossbedding are evident (Fisher, 1972; Oldale, 1968). The dominant lithologic material is granitic.

The material eroded from these deposits is transported south to Nauset Beach.

Protective Structures - None.

Shore Structures - Several buildings belonging to the National Park Service house the headquarters of the Cape Cod National Seashore. Roads and beach facilities, including boardwalks and stairs leading down the scarp to the beach, have also been built in the area.

The north end of Marconi Beach was the location of Guglielmo Marconi's permanent wireless radio station that established contact with Cornwall, England, in 1903. The station was dismantled in 1920 and subsequently the U.S. Army constructed Camp Wellfleet on the same site.

Figure 1-G21. Marconi Beach (looking north from second landing on stairs)

Figure 1-G22. Marconi Beach (looking south from second landing on stairs)

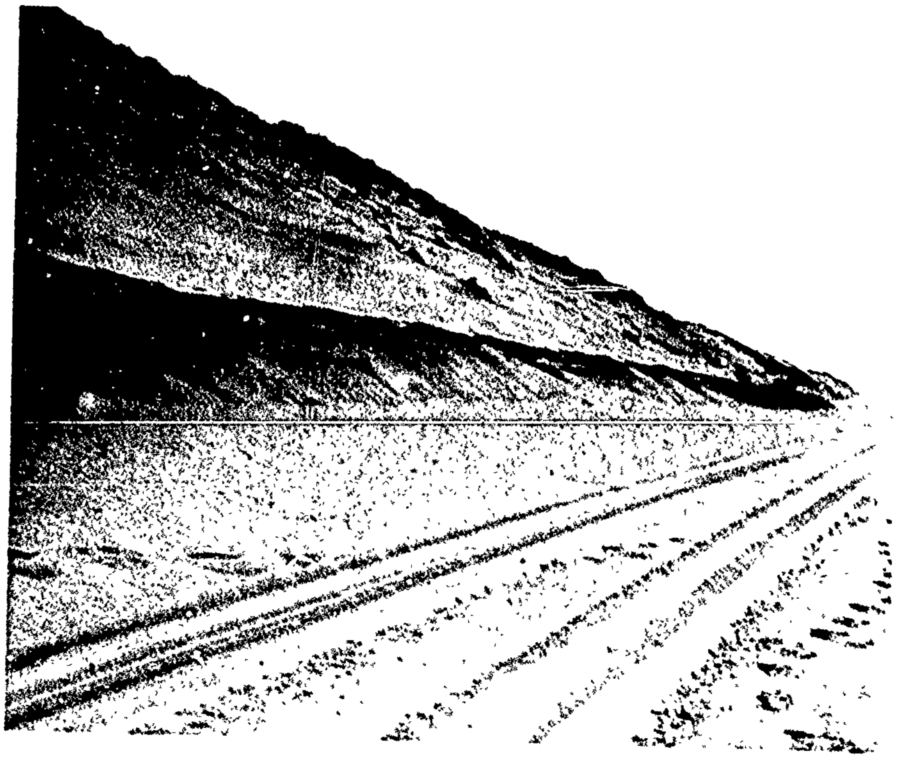


Figure 1-G23. Marconi Beach showing erosion-resistant bedding

Character of Development - Since the placement of Marconi's four steel towers in 1902, the scarp has eroded 170 feet, an average rate of 2.4 feet per year. The two concrete bases have crumbled to the beach below and the foundation of the powerhouse on the edge of the bluff is being eroded (Fisher, 1972). The location of the original towers at the Marconi Station site is now over 50 feet into the sea.

NAUSET BEACH

Location - Between the Wellfleet-Eastham town line and the southernmost extremity of Nauset spit southeast of Morris Island in Chatham. (A general description of the beach is presented here and descriptions of individual segments of the beach follow.)

Shore Length - Approximately 17.6 miles.

Ownership - Mixed; private, towns, and National Park Service.

Beach Use - Mostly swimming; some sections limited to campers and fishermen with beach buggies.

Public Facilities - Varied; discussed under separate beaches.

Beach Width - 50 to 1000 feet.

Composition of Shore - Fine-grained sand. North of Coast Guard Beach, Nauset Beach is a broad beach backed by large dunes. South of Nauset Bay, Nauset Beach is composed of two spits generated by the deposition of littoral drift eroded from the Eastham Plain scarp to the north. "North Spit" is the protion of beach extending from the Coast Guard Beach in Eastham south to the inlet to Nauset Harbor. "South Spit" encompasses the beach from the southerly edge of Nauset Harbor inlet to the termination of Nauset spit in Chatham, southeast of Morris Island.

North Spit is approximately 2.5 miles long, separating Nauset and Salt Pond Bays from the Atlantic Ocean. Fisher (1972) found that North Spit beaches can be divided into two types:

> 1. The first type, visible along southern Coast Guard Beach and south to halfway down the spit, is usually quite narrow with a steep foreshore slope. It is only about 100 feet wide, and at high and storm tides, waves reach the base of the foredunes. Average beach slope is 10 degrees with backshore slope being 16 degrees and the low tide nearshore slope less than 7 degrees. The backshore from the base of the foredune to the berm crest averages 60 feet with a 40-foot foreshore.

2. The second type, the southerly beach, develops in front of the area of incipient dunes. In contrast, this beach is wider (average width 250 feet) and less steep (less than 10 degrees) than the more northerly beach. It has a well-developed berm beyond which waves reach only during storms. The backshore width averages 150 feet to the berm crest, with the remaining 100 feet extending across the foreshore to the low water line.

Zimmerman (1963) identified five coastal sedimentary environments on the spit: The beach proper, an area of semi-stabilized dunes (the foredunes, an area of active incipient dunes, the eolian (wind-blown) flats, and the salt marshes.

Protective Structures - None; grass plantings and snow fences have been established in some areas.

Shore Structures - Varied for the length of the beach.

Character of Development - Numerous private summer cottages are located among the dunes.

Nauset Beach 1

Location - Between the Wellfleet-Eastham town line and a point 2000 feet north of Nauset Beach Lighthouse (Figure 1-G24).

Shore Length - 1.1 miles.

Ownership - National Park Service.

Beach Use - Mostly swimming.

Public Facilities - None.

Beach Width - 100 to 200 feet.

Composition of Shore - Fine-grained beach sand above and below high water backed by a 50-foot high, nearly vertical scarp. The top of the scarp is covered by small oak and pine trees.

Protective Structures - None.

Figure 1-G24. Nauset Beach 1 showing top of scarp covered with small oak and pine trees

Shore Structures - A paved road approximately 200 feet west of the edge of the scarp extends 0.9 miles north from Nauset Beach Lighthouse. The road continues north as a dirt road and jeep trail much closer to the edge of the dune, running down to the beach in places.

Character of Development - A few houses are located west of the road at the southern end of this portion of Nauset Beach.

Nauset Light Beach

Location - Between a point 2000 feet north of Nauset Beach Lighthouse to a point 200 feet south of the lighthouse (Figures 1-G25 through 1-G27).

Shore Length - About 0.4 miles.

Ownership - National Park Service.

Beach Use - Mostly swimming.

Public Facilities - Parking area on bluff 50 feet above beach; several wooden stairways provide access to beach; lifeguard protection provided for approximately 600 feet of beach during the summer.

Beach Width - 200 to 250 feet.

Composition of Shore - Fine-grained beach sand backed by 50-foot high bluff.

Protective Structures - None.

Shore Structures - Nauset Lighthouse, the only visual navigation aid between Chatham and Highland Light in Truro, was originally built as three fixed light towers in 1837. It was later replaced by a single revovling light. All the towers were destroyed as the eroding bank moved inland and Nauset Beach Lighthouse was moved 200 feet westward to its present location in 1923.

The parking lot is located only 5 to 12 feet from the edge of the dune and is in danger of being underminded as erosion continues.

Nauset Beach 2

Location - Between a point 200 feet south of Nauset Beach Lighthouse and Coast Guard Beach.

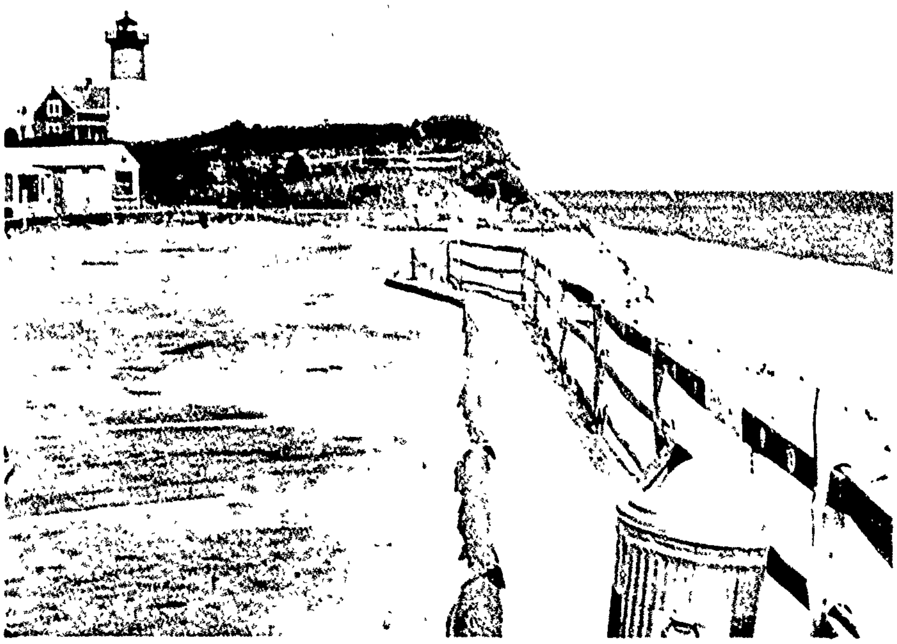


Figure 1-G25. Nauset Beach Lighthouse and beach, April 1977

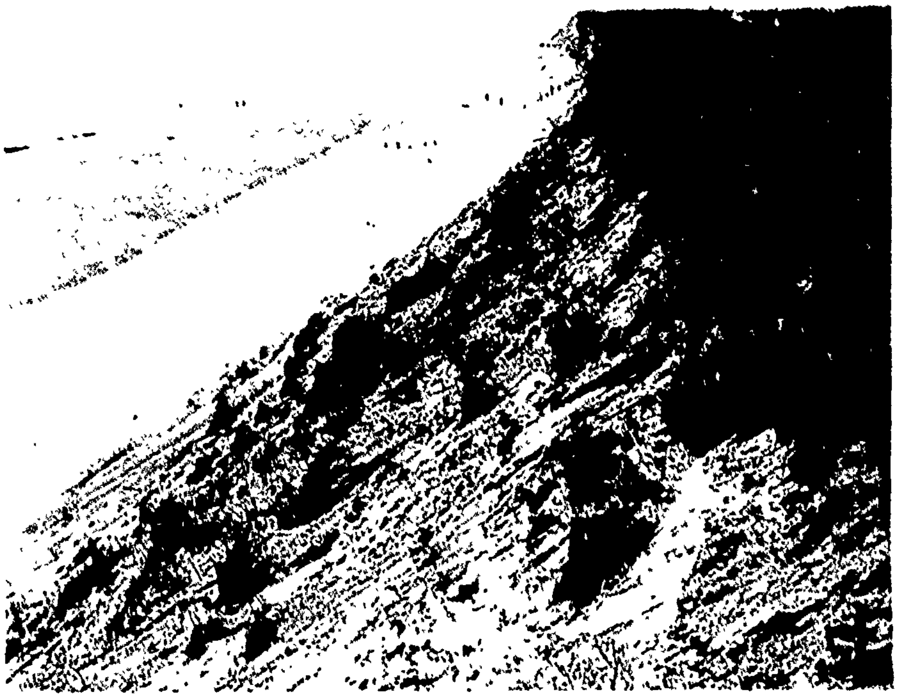


Figure 1-G26. Nauset Light Beach, from peak of dune shown in Figure 1-G25

Figure 1-G27. Nauset Light Beach showing fence along parking area, November 1977 (stairs in background are same as those seen in Figure 1-G26

Shore Length - Approximately 1 mile.

Ownership - National Park Service.

Beach Use - Mostly swimming.

Public Facilities - Large parking area and bathhouse at Coast Guard Beach.

Beach Width - 200 to 225 feet.

Composition of Shore - Fine beach sand. The northern half of the beach is backed by a steep 50-foot high scarp. In 1965, an exposure in the lower part of the scarp showed 10 feet of till, underlain by 2 feet of sand and gravel, underlain by a minimum of 3 feet of laminated silt (Fisher, 1972). The southern half of this portion of Nauset Beach is backed by low (10- to 20-foot high), narrow dunes that separate the ocean from a marsh leading to Nauset Bay.

Protective Structures - None.

Shore Structures - None.

Character of Development - A few houses are located 200 to 1000 feet from the edge of the dune.

Nauset Beach 3 (Coast Guard Beach)

Location - East of Nauset Bay; the northern end is part of Coast Guard Beach (Figure 1-G28 through 1-G30).

Shore Length - 0.6 miles.

Ownership - National Park Service.

Beach Use - Coast Guard Beach, the northern end, is used for swimming; the rest is limited to campers and fishermen with beach buggies.

Public Facilities - Large parking area and bathhouse at Coast Guard Beach until February 1978; lifeguard protection provided for approximately 1000 feet of beach during the summer.

Beach Width - 100 feet in summer, 50 to 75 feet in winter.

Composition of Shore - Fine beach sand above and below high water backed by 10- to 20-foot high dunes the length of the beach. These dunes are all that separate the ocean from Nauset Bay and the marshes that drain into the bay.

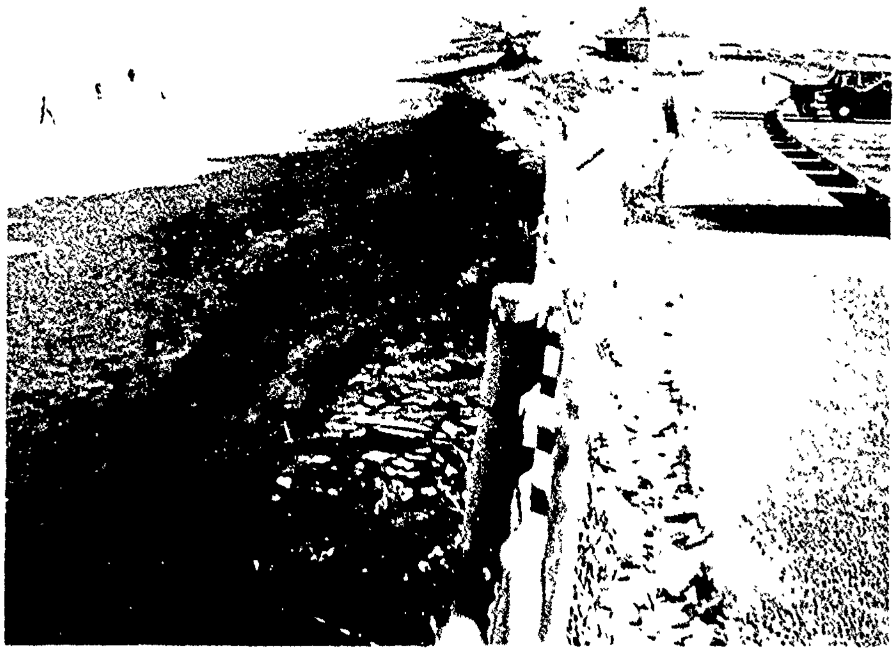


Figure 1-G28. Coast Guard Beach and bathhouse, April 1977

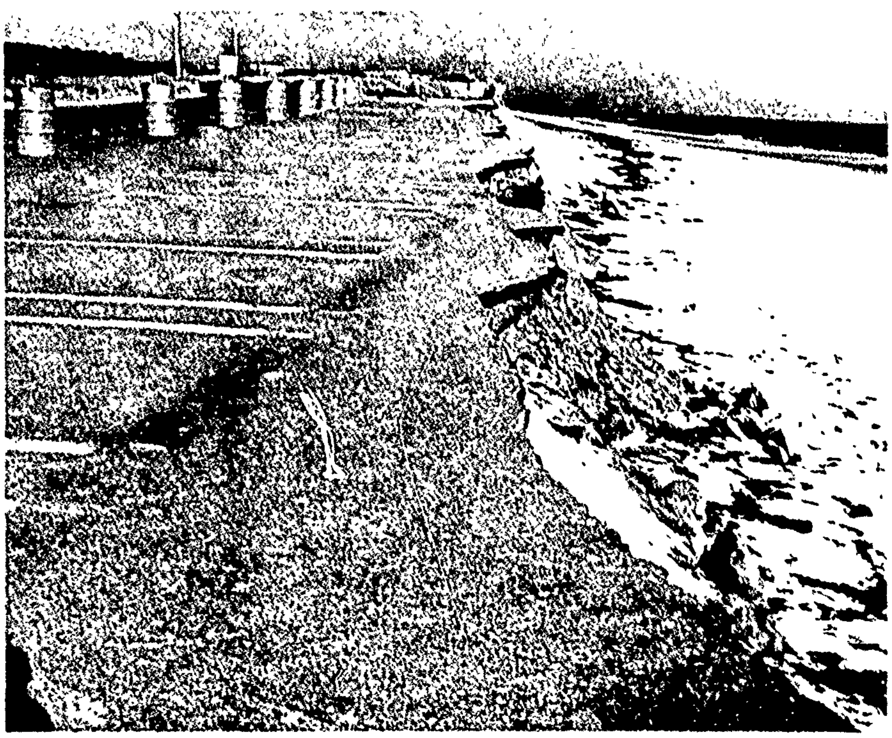


Figure 1-G29. Coast Guard Beach, May 1978

Figure 1-G30. Blowout on Nauset Beach 3, April 1977

Exposure of peat deposits 1 to 5 feet thick under the seaward side of the dunes on the spit is indicative of westward movement of the spit as a whole (Zeigler, 1956).

Protective Structures - None; dune grass plantings at Coast Guard Beach to control wind erosion.

Shore Structures - A few seasonal cottages are located on the dunes; a jeep trail runs along the base of the west side of the dunes.

A bathhouse and large parking lot were located close to the edge of the dune until the northeaster of 6-7 February 1978 damaged them both. Figures 1-G28 and 1-G29 show views of Coast Guard Beach as it was before and after the storm.

Character of Development - Federally and town-owned land is open to the public for bathing and fishing. Private land has several seasonal homes. The beach is used extensively during the summer by fishermen with beach buggies.

Nauset Beach 4

Location - Approximately 0.5 miles east southeast of Stony Island; extends to south end of North Spit at inlet to Nauset Harbor (Figures 1-G31 through 1-G33).

Shore Length - Approximately 2.3 miles.

Ownership - National Park Service and private.

Beach Use - Limited to campers and fishermen with beach buggies.

Public Facilities - None.

Beach Width - 50 to 100 feet for northern 1.3 miles southern 1.0 mile is spit ranging in width from 500 to 2000 feet.

Composition of Shore - Fine beach sand above and below high water; northern 1.5 miles of beach are backed by 10- to 20-foot high dunes; southern mile of spit is less than 10 feet above high water and is frequently overwashed.

Protective Structures - None; some fences erected to catch sand and raise dunes on North Spit.

Shore Structures - A few seasonal cottages are located behind the dune.

Figure 1-G31. Looking North at north spit from entrance to Nauset Harbor (dune in background is grass covered)

Figure 1-G32. Nauset Harbor Inlet from south end of north spit

Figure 1-G33. Nauset Harbor Inlet from south end of north spit looking toward Nauset Heights (view to west of Figure 1-G32; several sand bars are visible in channel)

Character of Development - Federally owned land is open to the public for bathing and fishing. Private land has several seasonal homes. The beach is used extensively during the summer by fishermen with beach buggies. The jeep trail continues along the spit behind the dunes for approximately 1.5 miles.

Nauset Beach 5

Location - Between Nauset Harbor and Orleans Beach (Figure 1-G34).

Shore Length - Approximately 1 mile.

Ownership - Town of Orleans.

Beach Use - Open to the public for recreation even though unprotected.

Public Facilities - None.

Beach Width - Northern 1/4 mile is a spit extending across the entrance to Nauset Harbor and ranging in width from 500 to 800 feet; southern 3/4 mile has 50-foot wide beach.

Composition of Shore - Fine beach sand above and below high-water mark with grass-covered, 10-foot dunes along southern 3/4 mile.

Protective Structures - None.

Shore Structures - None.

Character of Development - There is no development along the shore.

Orleans Beach

Location - Three-fourths of a mile south of Nauset Heights (Figure 1-G35).

Shore Length - 0.1 miles.

Ownership - Town of Orleans.

Beach Use - Public swimming.

Public Facilities - Bathhouse and refreshment stand on the beach (Figure 1-G36); large parking area.

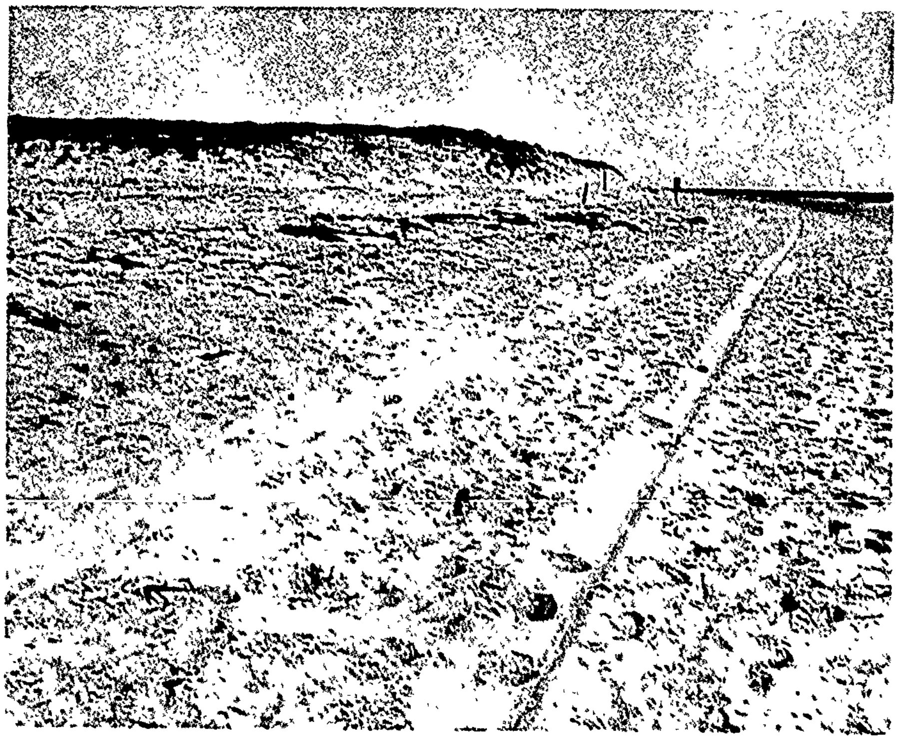


Figure 1-G34. South end of Nauset Beach 5

Figure 1-G35. Orleans Town Beach, November 1977 (seaweed indicates high water mark)

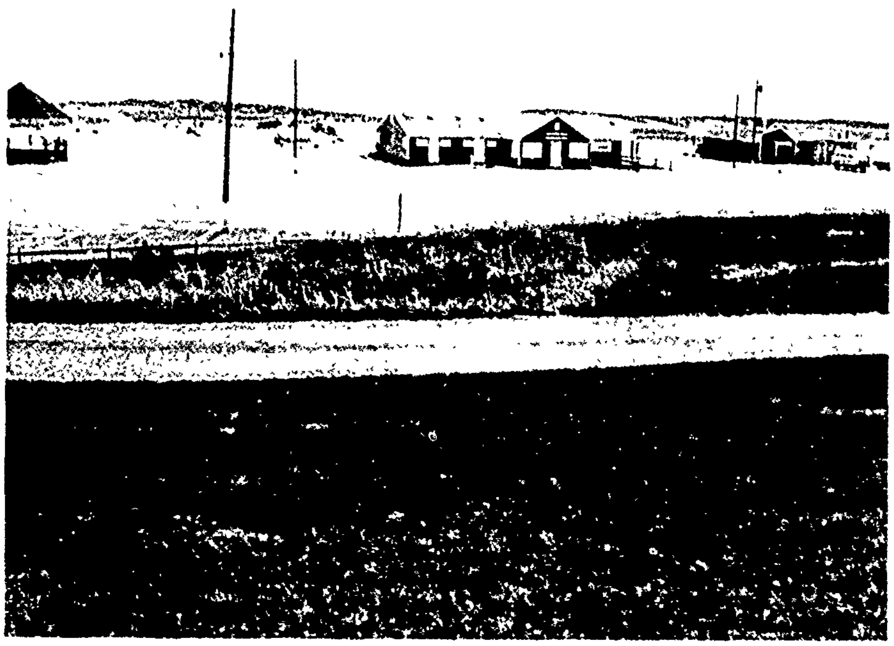


Figure 1-G36. Orleans Town Beach bathhouse and refreshment stand

Beach Width - 130 feet.

Composition of Shore - Fine beach sand above and below the high-water mark with 10-foot high, grass-covered dunes along the beach.

Protective Structures - None.

Shore Structures - The refreshment stand, bathhouse, and parking lot are immediately behind the dune.

Character of Development - The town facilities are the only development close to the beach.

Nauset Beach 6

Location - Between the south end of Orleans Beach and a point 1 mile east of Sampson Island (Figure 1-G37).

Shore Length - Approximately 2 miles.

Ownership - National Park Service.

Beach Use - Limited to campers and fishermen with beach buggies.

Public Facilities - None.

Beach Width - 50 to 200 feet.

Composition of Shore - Fine beach sand above and below high water with 10- to 20-foot dunes above high water.

Protective Structures - None.

Shore Structures - A few seasonal cottages are located south of and on the southeast side of Little Pochet Island (Figure 1-G38). They are reached by jeep trail.

Character of Development - Development is minor in this area.

Nauset Beach 7

Location - From a point 1 mile east of Sampson Island to the former Old Harbor Life Saving Station Site, which is about 1 mile east-southeast of Allen Point (Figure 1-G39).

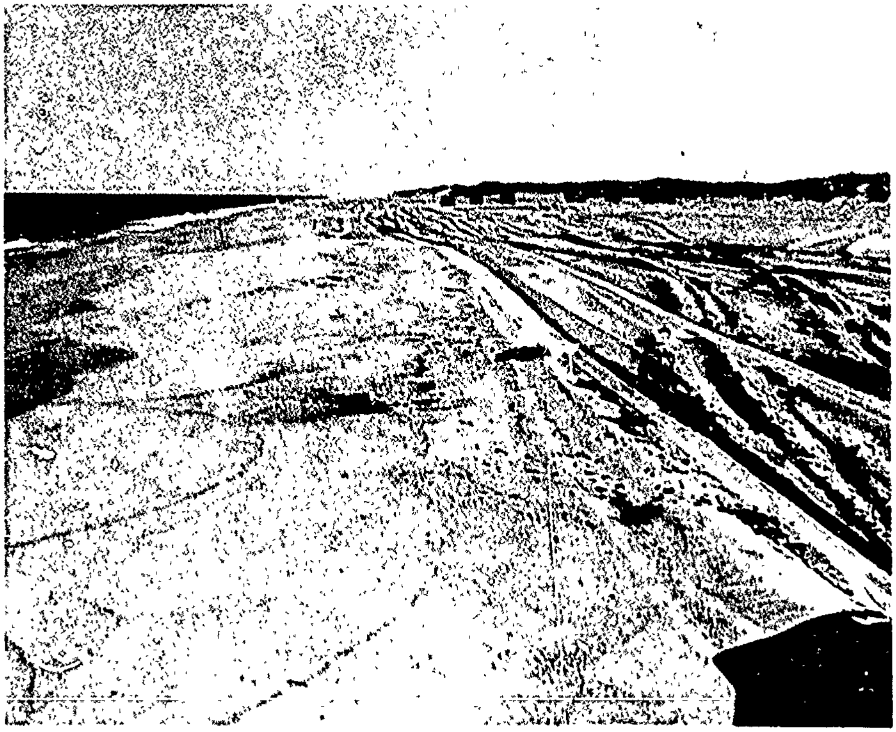


Figure 1-G37. Nauset Beach 6 at Little Pochet Island

Figure 1-G38. Nauset Beach 6 (looking south from Little Pochet Island)

Figure 1-G39. South end of Nauset Beach 7

Shore Length - 5.7 miles.

Ownership - Private, Town of Chatham, and U.S. Government, all under jurisdiction of Cape Cod National Seashore, National Park Service.

Beach Use - Limited to campers and fishermen with beach buggies.

Public Facilities - None; beach is open to public but is only accessible by beach buggy or boat.

Beach Width - Beach extends on both east and west sides of the spit, which ranges from 500 to 3200 feet in width. Actual beach width varies extensively with the season; beach width varies from 10 to 30 feet in winter to 130 to 180 feet in summer.

Composition of Shore - Fine beach sand above and below high water with 10- to 20-foot high, grass-covered dunes above high water.

On the basis of data from six sampling stations established at 1-1/2-mile intervals, Felsher (1963) determined that as sand moves south along Nauset Beach away from the source there is no significant decrease of median grain size. However, as the sand moves south along Nauset Beach there is a significant change in sorting with the better sorted materials to the south away from the source. The sorting coefficient at the northern end of Nauset Beach was 0.425, while it was 0.259 at the southern end.

Protective Structures - No permanent structures; however private groups and individuals have experimented with sand fence, discarded Christmas trees, and grass plantings for dune construction and sand retention. (See the section entitled "Inhibiting Erosion" for a description of dune restoration projects in this area.)

Shore Structures - Northeast of Allen Point is a cluster of seasonal cottages, accessible only by boat or beach buggy.

Character of Development - No significant development.

Nauset Beach 8

Location - From the former Old Harbor LIfe Saving Station Site to a point 0.75 miles east of Chatham Lighthouse (Figure 1-G40).

Shore Length - 1.8 miles.

Ownership - Private, town of Chatham, and U.S. Government, all under jurisdiction of Cape Cod National Seashore, National Park Service.

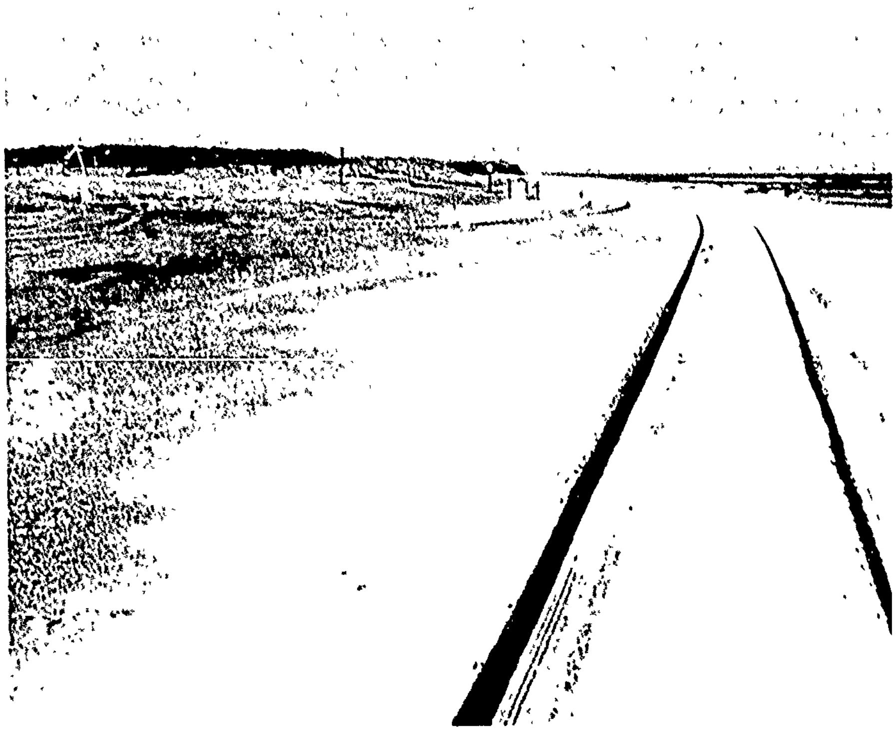


Figure 1-G40. Nauset Beach 8 opposite Chatham Lighthouse

Beach Use - Limited to campers and fishermen with beach buggies.

Public Facilities - None; beach is open to public but is only accessible by beach buggy or boat.

Beach Width - Beach extends on both east and west sides of the spit, which ranges from 500 to 2100 feet in width. Actual beach width varies extensively with the season - from 10 to 30 feet in winter to 130 to 180 feet in summer.

Composition of Shore - Fine beach sand above and below high water with some low-lying dunes in the most northern areas.

Protective Structures - No permanent structures; however, private groups and individuals have experimented with sand fence, discarded Christmas trees, and grass plantings for dune construction and sand retention.

Shore Structures - Several buildings are located in the vicinity of the Old Harbor Life Saving Station site. Several more seasonal cottages are located 1/4 to 1/2 mile to the southwest on the harbor side of the spit.

Character of Development - The entire shoreline is open to the public for swimming and fishing. There are several privately owned properties with seasonal cottages. The beach is used extensively during the summer by fishermen with beach buggies.

Tip of Nauset Beach

Location - From a point east of Chatham Lighthouse to the southern end of the spit (Figure 1-G41).

Shore Length - 1.6 miles; will undoubtedly be longer as accretion continues.

Ownership - Town of Chatham.

Beach Use - Limited to campers and fishermen with beach buggies.

Public Facilities - None.

Beach Width - Beach extends on both east and west sides of the spit, which ranges from 600 to 1500 feet in width.

Composition of Shore - Fine beach sand above and below high water; low dunes along center of spit.

Protective Structures - None.

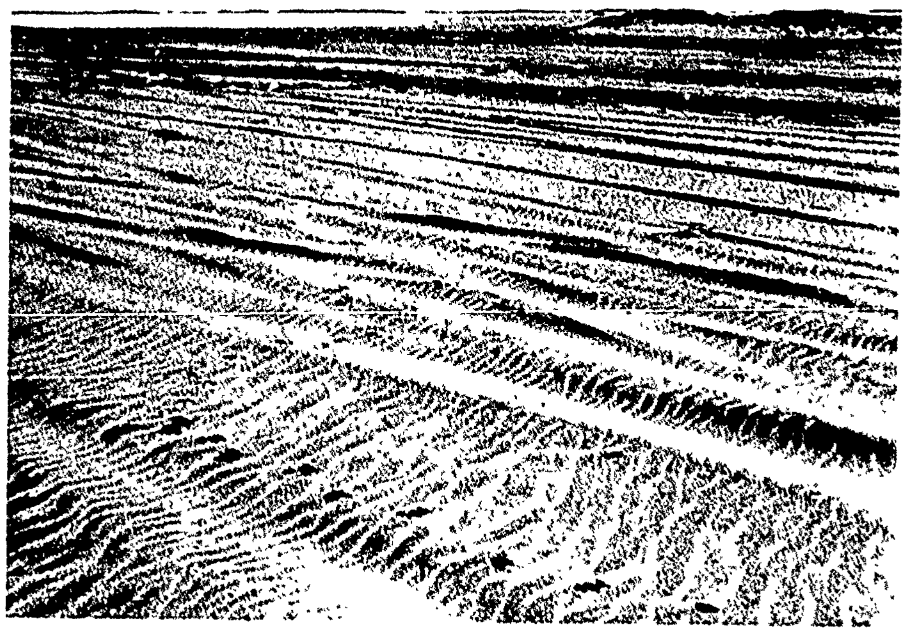
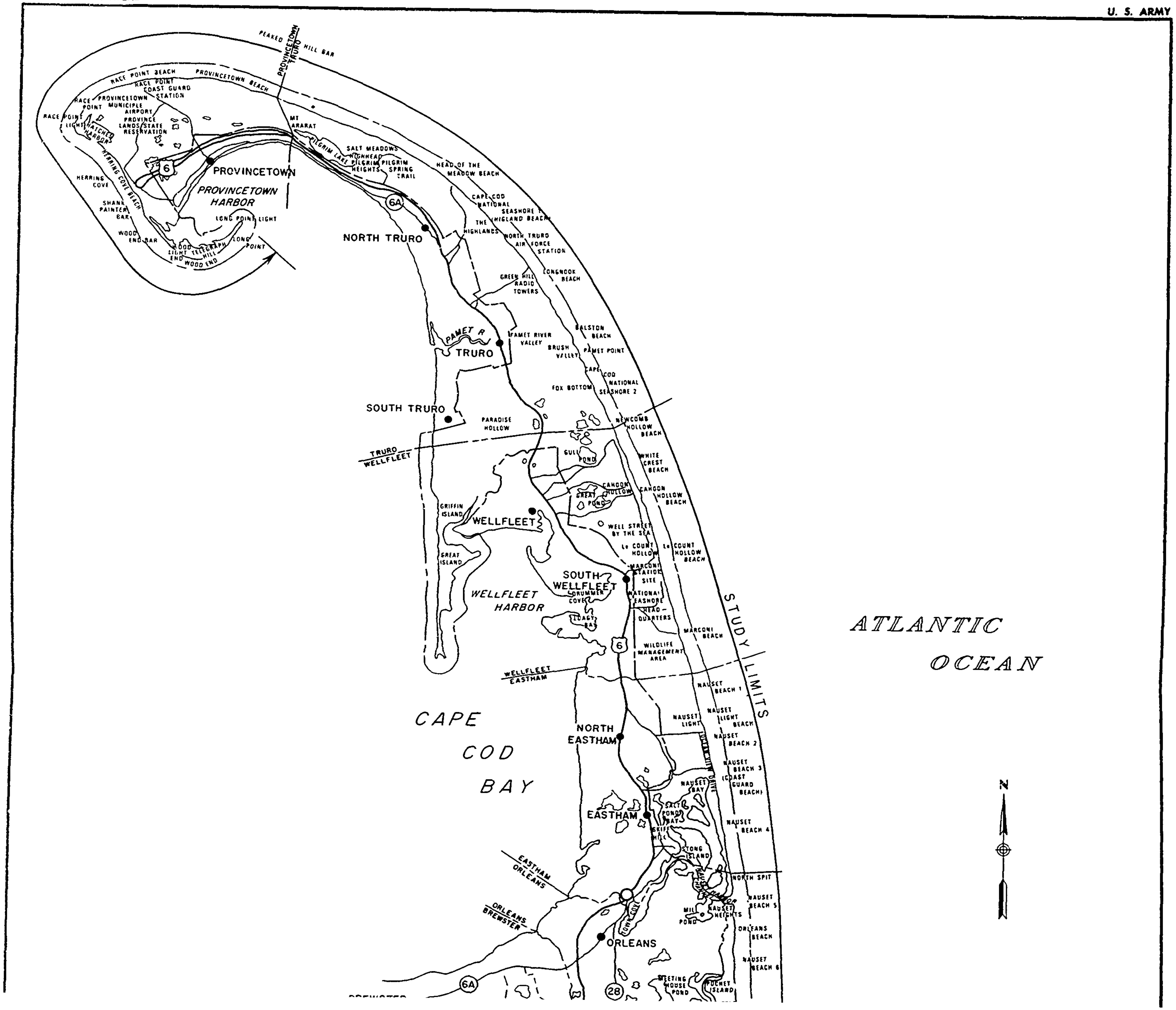


Figure 1-G41. Tip of Nauset Beach looking west toward Morris Island

Shore Structures - None.

Character of Development - Broad flat sand spit.


ATLANTIC OCEAN
CAPE COD BAY
STUDY LIMITS
PROVINCETOWN
PROVINCETOWN HARBOR
NORTH TRURO
TRURO
SOUTH TRURO
WELLFLEET
SOUTH WELLFLEET
WELLFLEET HARBOR
NORTH EASTHAM
EASTHAM
ORLEANS
PEAKED HILL BAR
PROVINCETOWN TRURO
RACE POINT BEACH
PROVINCETOWN BEACH
RACE POINT COAST GUARD STATION
RACE POINT
PROVINCETOWN MUNICIPLE AIRPORT
PROVINCE LANDS STATE RESERVATION
HATCHES HARBOR
HERRING COVE BEACH
HERRING COVE
SHANK PAINTER BAR
WOOD END BAR
WOOD END LIGHT
TELEGRAPH HILL
LONG POINT LIGHT
LONG POINT
MT ARARAT
PILGRIM LAKE
SALT MEADOWS
PILGRIM SPRING TRAIL
HEAD OF THE MEADOW BEACH
CAPE COD NATIONAL SEASHORE 1
HIGLAND BEACH
THE HIGHLANDS
NORTH TRURO AIR FORCE STATION
GREEN HILL RADIO TOWERS
LONGNOOK BEACH
PAMET R
PAMET RIVER VALLEY
BRUSH VALLEY
BALSTON BEACH
PAMET POINT
CAPE COD NATIONAL SEASHORE 2
FOX BOTTOM
PARADISE HOLLOW
NEWCOMB HOLLOW BEACH
TRURO WELLFLEET
GULL POND
WHITE CREST BEACH
CAHOON HOLLOW
GREAT POND
CAHOON HOLLOW BEACH
GRIFFIN ISLAND
GREAT ISLAND
WELL STREET BY THE SEA
Le COUNT HOLLOW
Le COUNT HOLLOW BEACH
MARCONI STATION SITE
DRUMMER COVE
NATIONAL SEASHORE HEAD-QUARTERS
MARCONI BEACH
WILDLIFE MANAGEMENT AREA
WELLFLEET EASTHAM
NAUSET BEACH 1
NAUSET LIGHT
NAUSET LIGHT BEACH
NAUSET BEACH 2
NAUSET BEACH 3 (COAST GUARD BEACH)
NAUSET BAY
SALT POND BAY
SKIFF HILL
NAUSET BEACH 4
STONG ISLAND
NORTH SPIT
NAUSET HARBOR
NAUSET BEACH 5
MILL POND
NAUSET HEIGHTS
ORLEANS BEACH
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SECTION H

SUMMARY

SUMMARY

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CAPE COD IN THE PAST

Cape Cod is a relatively new feature in terms of geologic time, having been formed by glaciers that left the area about 12,000 years ago. The warming trend that caused the ice to retreat liberated large quantities of water formerly incorporated in the ice sheets. The water released from the glaciers flowed into the ocean, causing sea level to rise. At that time, the land we know as Provincetown did not exist, and the outer coast of Cape Cod was east of its present location. By about 3,500 years ago the rising sea had approached its present level (Strahler, 1966). As sea level rose, Georges Bank and Nantucket Shoals began to submerge. When the depth of water in these areas was sufficient to allow the passage of waves, waves coming from the southeast and passing over Georges Bank eroded the eastern shores of Cape Cod and transported materials northward to begin forming the Provincelands hook.

Waves also caused the original shoreline (which was probably irregular) to retreat to the gently curving coastline apparent today. Wave attack was concentrated on the headlands, causing them to erode more rapidly than adjoining bays. Sand eroded from the headlands was transported along the coast, filling bays and building barrier beaches and spits.

CAPE COD TODAY

Coastline changes visible by comparing historical and recent aerial photographs show that the processes of erosion and accretion are continuing on Cape Cod's eastern shores. From 1938 to 1974 Long Point, Wood End, Herring Cove Beach and Race Point underwent erosion, while accretion occurred along most of the coastline from Race Point to the Pilgrim Heights Area (Gatto, 1975). The Provincetown coastline has grown at the expense of the Highlands scarp which has been retreating at an average rate of 2.6 feet per year (Zeigler et al, 1964). Erosion has predominated from Head of the Meadow Beach to Highland Light and from north of Ballston Beach to Monomoy (Gatto, 1975). Not all of the sand eroded from the scarp travels north to Provincetown; some travels south to supply the Nauset Beach complex and Monomoy Island. It is not known with certainty where the transition from northward to southward transport occurs, but wave refraction analysis suggests LeCount Hollow Beach as the most likely location (Cornillon et al, 1976).

Factors that affect erosion and accretion on the Cape today include storms, waves, winds, tides and the presence of man. Hurricanes and northeasters, the typical storms that threaten Cape Cod, have eroded large quantities of material in short periods of time. Storms are effective agents of erosion because waves combine with storm surge to reach portions of the beach or scarp not normally subjected to wave attack. Even storms that do not reach the dunes or scarp may cut back the beach, leaving the backshore more vulnerable to subsequent storms.

Large amounts of beach material can also be moved by waves during moderate weather conditions. When wave fronts are parallel to the beach, sand moves landward and seaward but does not move laterally along the beach; however, if the waves strike the coast at an angle, they cause sand to be moved along parallel to the shoreline. Known as longshore transport, this process is responsible for removing sand from one area and supplying it to another area; erosion of the Highlands and accretion at Race Point are evidence of longshore transport.

Wind contributes to erosion by producing waves (particularly during storms), by piling water against the coast and by direct action on the sand itself. Under the wind's influence, sand can be moved along the beach or inland away from the beach. Inland movement of windblown sand at Race Point is building the Provincelands dunes and causing Hatches Harbor to shoal. Along Nauset Beach in Eastham, Orleans and Chatham, windblown sand is shoaling Nauset Harbor, Pleasant Bay and Chatham Harbor and is covering the marshes.

Tides create currents that prevent inlets and harbor entrances from being closed by the sand moving along the coast. A flooding tidal current may also carry fine materials through an inlet to build marshes (Strahler, 1966).

Man's presence on Cape Cod during the last 350 years has led to another form of erosion, cultural, which has accelerated the whole process. Colonial man disturbed the balance by overgrazing cattle on the dune grasses and removing the trees. Modern man has damaged the vegetation by careless use of beach buggies and pedestrian abuse of the dunes. In an attempt to remedy some of the areas affected by man-made and natural erosion, the U.S. Army Corps of Engineers and local groups on the Cape have undertaken dune building and stabilization programs involving sand fencing and beach grass planting. These efforts have successfully built artificial dunes in washover areas.

Structures threatened by erosion have included government installations such as lighthouses and life saving stations that had to be placed in close proximity to the coast. The advancing shoreline has reclaimed some of the structures; others have been moved to temporarily safer ground. As erosion continues, however, more private residences will be jeopardized and will require moving. Construction in most of the threatened areas is controlled by the National Park Service through the Cape Cod National Seashore. Land use regulations such as those imposed in the National Seashore should be employed to prevent construction in areas particularly vulnerable to erosion.

Loss of private property is not the only economic concern associated with erosion. The outer Cape and its beaches attract year-round residents, summer residents, short-term vacationers and day trippers to the Cape. Income generated by the Cape's many visitors constitutes a substantial part of the Cape's economy, which would be seriously affected if either erosion or attempts to inhibit erosion diminished the recreational or scenic value of the Cape's beaches.

Erosion threatens in other ways. For example, if the dunes separating the Pamet River from the Atlantic Ocean are permanently breached, salt water could invade the freshwater wetlands of the Pamet River valley and infiltrate the ground water and wells. Washovers in the area of Coast Guard Beach and Nauset Beach (south of Nauset Heights) could cause an influx of salt water into the brackish bays behind the barrier beach. If a break in the spit were established, the change in conditions such as salinity, temperature, circulation and sand deposition would endanger the shellfish beds in the bays. Sand movement has also caused problems at the entrances to Nauset and Chatham harbors. Few boats can navigate the treacherous, shifting shoals that separate the harbors from the Atlantic. Poor navigational conditions diminish the harbors' value as homeports for deepwater fishing vessels.

Nauset Harbor inlet suffers depositional rather than erosional problems. Large quantities of sand eroded from the marine scarp to the north are in transit past Nauset Harbor inlet. Some of the sand feeds the spits north and south of the inlet and deposits in the inlet, itself. Due to the movement of the sand, the inlet shifts seasonally and sometimes with every change in tide. In 1969 the average depth of the entrance at low water was 3 feet, and the location of the channel was constantly changing (U.S. Army Corps of Engineers, 1969). Even though Nauset Harbor is the only harbor on the Cape's Atlantic coast between Provincetown and Chatham, its value as a harbor of refuge during storms is greatly diminished because the inlet is navigable only by small boats.

Shoaling at Nauset Harbor has not been restricted to the inlet; deposition has also occurred in the harbor, coves and bays. Erosion of the barrier beach has also contributed to the shoaling problem in these areas. The decreased depth of the inlet and inner harbor areas reduces tidal flushing, a natural process that reduces stagnation in the bays and coves.

Possible solutions to the problems in the Nauset Harbor area would be extremely costly due to the large amounts of sand that would have to be moved annually. On an economic basis, the improvements cannot be justified (U.S. Army Corps of Engineers, 1969).

Like Nauset Harbor inlet, Chatham Harbor inlet experiences shoaling problems due to sand deposition. Sand added to the tip of Nauset Beach has caused the inlet to migrate south. Chatham Bar, which stretches across the inlet, is covered by only 3 to 4 feet of water at low water. Favorable tides and wind conditions are needed by boats attempting to cross the bar. These restraints hamper the commerical fisherman homeported in Aunt Lydia's Cove who must navigate the inlet to reach offshore fishing

grounds. Even within the bay, which is located behind the barrier beach, navigation is hampered by the presence of shoals and the wandering of channels (U.S. Army Corps of Engineers, 1968).

Improvements in the navigational conditions at Chatham are favored by the local populace. They feel that stabilization of an inlet through Nauset Beach might reduce the threat of loss of life; benefit commercial fishing interests, recreational boating and the U.S. Coast Guard; provide a harbor of refuge for boats cruising off the Atlantic coast; and relieve stagnation of bay waters (U.S. Army Corps of Engineers, 1968). In 1968 the Corps of Engineers determined that improvements were needed in this area and that the improvements could be justified on an economic basis. However, a lo . contribution of nearly $5 million would have been required in 1968. That figure will undoubtedly rise with delays and inflation.

Erosion problems are aggravated by disregard for the beach, scarp and dunes. In some areas access to the beach is uncontrolled, and beachgoers walk up and down dunes and banks at any convenient location. Beach buggy drivers who stray from designated trails and permitted areas damage beach grasses, leaving the dunes vulnerable to further erosion. Overland runoff from parking areas, access roads and adjacent areas increases the erosion; at some locations drainage pipes empty directly onto the beach or the face of the bank, thereby accelerating the erosion rate.

CAPE COD IN THE FUTURE

Shoreline changes during the next 50 years will probably include continuing erosion of Provincetown's western shore, accretion on its northern coast and further retreat of the eastern Cape Cod shoreline. Annual Erosion rates of 1 to 3 feet (increasing northward) are anticipated on the coastline from Long Point to Race Point. Accretion rates up to 3 feet per year are expected on the northern shore of Provincetown. Erosion at rates up to 3-1/2 feet per year is predicted for the marine scarp area on the eastern coast of Truro, Wellfleet and Eastham. On the southern portions of Nauset Beach, erosion rates may be even higher. If these rates, predicted by the wave refraction analysis, prevail for the next 50 years, the eastern shores will lose 50 to 150 feet in most areas. Up to 150 feet of accretion should occur north of the Provincelands.

Erosion (particularly from storms) may cause serious problems in areas where low dunes protect upland features. Areas of risk include Head of the Meadow Beach where dunes protect Salt Meadow; Ballston Beach where dunes separate the Atlantic Ocean from the head of the Pamet River; and Coast Guard Beach

where low dunes on the barrier beach protect the ecology of Nauset Bay. Barrier beaches at Nauset Harbor and Nauset Beach south of Nauset Heights protect the bays behind them; at the same time, however, the barrier beaches are encroaching on the marshes behind them at approximately the same rate at which the scarp is eroding.

The great blizzard of 1978 seriously eroded sections of shoreline along the outer Cape. At Head of the Meadow Beach, the dunes have been cut to within 10 feet of mean sea level. Waves overtopping the dunes could reach Salt Meadow. At Coast Guard Beach, erosion could produce a breakthrough to Nauset Bay, harming the existing ecology in the bay. At Ballston Beach, storm waves have overtopped the low dunes, reaching the marshland at the river head. The Pamet Harbor Committee has expressed concern that unless the dune is reinforced, the ocean will eventually break through; the ensuing salt flood conditions would completely alter the appearance and physical composition of the freshwater valley and permeate the freshwater table, thereby destroying well systems in the area and lowering property values.

Barrier beaches north and south of Nauset Harbor inlet and Nauset Beach in the Pleasant Bay-Chatham Harbor area prevent the colder, saltier waters of the Atlantic Ocean from mixing with the brackish waters of the inner harbors and bays. Barrier beaches, however, are prone to washovers; critical erosion of a washover could establish a break in the beach and permit free communication between the bay and the ocean. Such breakthroughs are possible along much of Nauset Beach.

Sand carried by the wind or by water travelling over washovers can cover shellfish beds and marshy areas in the bays as well as shoal navigational channels.

The erosion problem pertaining to structures was summarized in 1973 by Paul P. Hanson, Jr., Chairman of the Board of Selectmen in Orleans:

> We are fortunate that our grandparents knew better than to build their house right on the beachfront ... and we are not faced with 400 substantial sizable dwellings to have to protect. The orderly retreat of the shorefront so far has caused little hardship to any person. But we are getting to the point where it is going to.

Structures such as lighthouses and life saving stations were intentionally located close to the water. Erosion has forced some of these structures to be moved inland, whil others have toppled into the sea. Structures moved or lost include the Pamet River, Nauset and Old Harbor Life Saving Stations; the tower bases at Marconi Station site; Nauset Lighthouses (the "Three Sisters of Nauset") and the single lighthouse that replaced them; the asphalt area at Herring Cove Beach; the parking area at Nauset Beach; and the bathhouse and parking facilities at Coast Guard Beach. Any structures located within several hundred feet of the shore in eroding areas will be endangered during the next 50 years.

If an erosion rate of 3 feet per year is presumed to exist in the future, the narrow parts of the outer Cape (at Highland Light and south of Wellfleet), where the width is about 10,000 feet, could erode through in approximately 3000 years. The wider portions of the outer Cape (20,000 to 25,000 feet) would be expected to erode through in 6000 to 8000 years (Johnson, 1925, cited in Fisher, 1972). In the foreseeable future, a breakthrough could occur at Ballston Beach, Truro, which would join Cape Cod Bay with the Atlantic Ocean through the Pamet River valley.

In the following appendix, some possible alternatives for slowing the erosion rate on the outer Cape are considered.

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APPENDIX 2

PLANS OF CONSIDERED IMPROVEMENTS WITH ATTENDANT COSTS AND ANNUAL CHARGES

PREPARED BY THE NEW ENGLAND DIVISION

CORPS OF ENGINEERS

DEPARTMENT OF THE ARMY

PLANS OF CONSIDERED IMPROVEMENTS

WITH

ATTENDANT COSTS AND ANNUAL CHARGES

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PLATES

Table 1-F6. Increase in residential dwelling units, 1970-1975

TOWNSHIP	1970	1975	PERCENT OF INCREASE
Provincetown	2,812	2,945	4.7
Truro	1,760	1,969	11.9
Wellfleet	1,933	2,318	19.9
Eastham	2,687	3,334	24.1
Orleans	2,229	2,914	30.7
Chatham	3,943	4,638	17.6
Totals:			
Outer Cape	15,364	18,118	17.9
Barnstable County	67,036	88,110	31.4

Source: Town Building Inspectors' Report, compiled by Cape Cod Planning and Economic Development Commission

INTRODUCTION

This section presents cost estimates for plans to protect Cape Cod's easterly shores. The plans considered are generally similar to those that have been proposed for other areas on the Atlantic Coast, Gay Head Cliffs on Martha's Vineyard, Massachusetts for example (New England Division, Corps of Engineers, 1973). General features of the stuctures are described, and a preliminary economic analysis is presented. Any plan found to be justified by the economic analysis would require further investigation to determine the design criteria and environmental effects of the proposed plan. These aspects are not treated in this report.

The plans encompass most of the outer Cape Cliffs where erosion has been pronounced, they are stretching from near the Provincetown-Truro town line to south of Nauset Light (Figure 2-1). The shore to the north is generally characterized by accretion making protective structures unnecessary. Migrating spits are typical of the area south of the plan limit making the effects of protective structures unpredictable.

The plans discussed in the following sections include a breakwater in the offshore zone, three structures that separate the water from the shore (nearshore stone mound, concrete/rubble mound and a rock revetment), three methods that utilize groins and/or sandfill to stabilize the beach, and a plan for dune stabilization.

Within the study limits the ultimate goal of each improvement (except dune stabilization) is to prevent further erosion of the cliffs behind the beach. This can be accomplished by protecting the cliffs themselves or by protecting the beaches in front of the cliffs. The considered improvements designed to protect the beach also protect the cliffs, which are least vulnerable to wave action when the beaches are full. In some of the proposed structures, however, protecting the cliffs would involve loss of the beaches as they exist today.

Initial costs and annual charges for the considered plans of improvement are presented in this appendix. Benefits and disadvantages are addressed in Appendix 3. Costs and charges are calculated based on 1978 prices and the current Federal interest rate of 6-7/8 percent. Principal features of the plans are shown on Plate 2-1; a cost summary is presented in Table 2-1. (Both Plate 2-1 and Table 2-1 are located at the end of this appendix.)

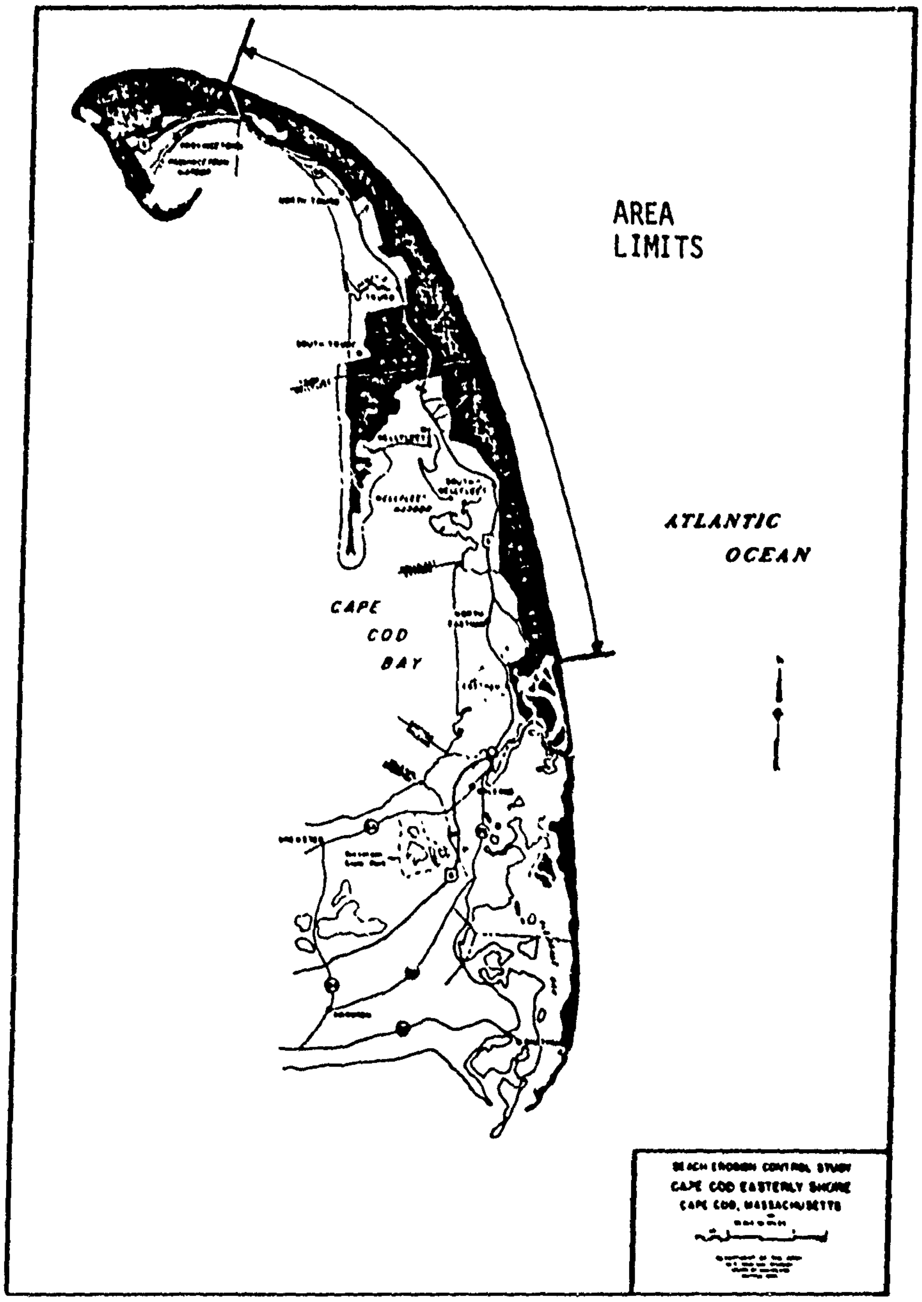


Figure 2-1. Area limits for plans of considered improvement

PLAN I ROCK REVETMENT

Plan I consists of a rock revetment located along the base of the dunes extending 100,000 feet parallel to the shore. As Figure 2-2 shows, the revetment is constructed on a gravel base covered by underlayer stone and armor stone.

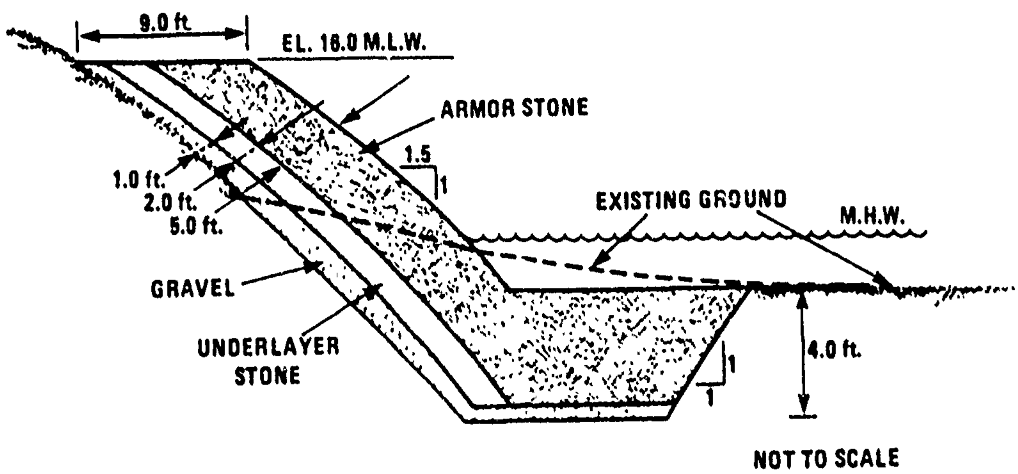


Figure 2-2. Plan I - Rock Revetment

ESTIMATED COSTS FOR PLAN I - ROCK REVETMENT

First Cost		
Stone (1,000,000 tons @ $25.00/ton)		$ 25,000,000
Contingencies		5,000,000
	Subtotal	30,000,000
Engineering and Design		3,000,000
	Subtotal	33,000,000
Supervision and Administration		2,970,000
Total First Cost		$ 35,970,000
Federal Share of Cost (50%)		$ 17,985,000
Non-Federal Share of Cost (50%)		$ 17,985,000
Annual Charges		
Federal Investment		
Interest and Amortization (0.07131 x $17,985,000)		$ 1,283,000
Total Federal Annual Charge		$ 1,283,000
Non-Federal Investment		
Interest and Amortization (0.07131 x $17,985,000)		$ 1,283,000
Revetment Maintenance (10,000 tons @ $40.00 per ton)		400,000
Total Non-Federal Annual Charge		$ 1,683,000
Plan I: Total Annual Charge		$ 2,966,000

PLAN II NEARSHORE STONE MOUND

Plans I, II and IV describe structures designed to separate land and water areas. Their primary purposes is protection of land and upland property from damage by waves. These structures also may serve an incidental function as retaining walls on a receding coastline. While protecting the immediate area, they may cause problems in adjacent areas by accelerating erosion. In addition, loss of material at the foot of the structure may be accentuated (U.S. Army Coastal Engineering Research Center, 1975).

Plan II consists of a nearshore stone mound located about 150 feet seaward of the base of the dune or bluff extending 100,000 feet parallel to the beach.

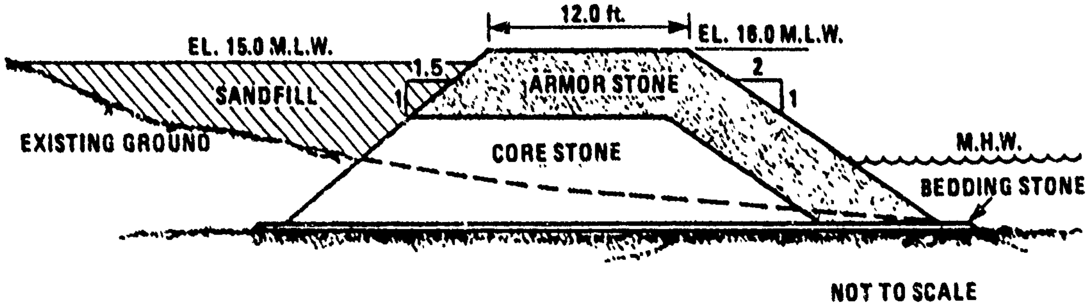


Figure 2-3. Plan II - Nearshore Stone Mound

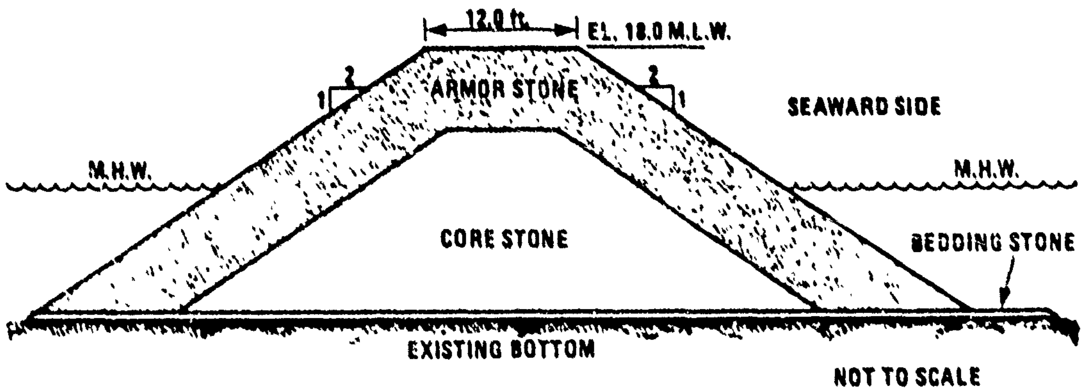
ESTIMATED COSTS FOR PLAN II - NEARSHORE STONE MOUND

First Cost		
Stone (4,000,000 tons @ $25/ton)		$100,000,000
Sand (470,000 cubic yards)		2,350,000
	Subtotal	102,350,000
Contingencies		20,400,000
	Subtotal	122,750,000
Engineering and Design		12,000,000
	Subtotal	134,750,000
Supervision and Adminstration		12,250,000
Total First Cost		$147,000,000
Federal Share of Cost (50%)		$ 73,500,000
Non-Federal Share of Cost (50%)		$ 73,500,000
Annual Charges		
Federal Investment		
Interest and Amortization (0.07131 x $73,500,000)		$ 5,241,000
Total Federal Annual Charge		$ 5,241,000
Non-Federal Investment		
Interest and Amortization (0.07131 x $73,500,000)		$ 5,241,000
Stone Mound Maintenance (40,000 tons @ $40.00 per ton)		1,600,000
Total Non-Federal Annual Charge		$ 6,841,000
Plan II: Total Annual Charge		$ 12,082,000

PLAN III OFFSHORE STONE BREAKWATER

An offshore breakwater is designed to protect an area from wave action by dissipating the force of the waves (U.S. Army Coastal Engineering Research Center, 1975). Erosion and longshore transport may be lessened but the presence of the breakwater may also decrease the supply of material to downdrift beaches.

Plan III is a stone breakwater located approximately 1200 feet offshore and extending 100,000 feet parallel to the shore. The breakwater consists of a core enclosed in armor stone as shown in Figure 2-4.



.igure 2-4. Plan III - Offshore Stone Breakwater

ESTIMATED COSTS FOR PLAN III - OFFSHORE STONE BREAKWATER

First Cost

Stone (14,000,000 tones @ $25.00/ton)		$ 350,000,000
Contingencies		70,000,000
	Subtotal	420,000,000
Engineering and Design		42,000,000
	Subtotal	462,000,000
Supervision and Administration		41,000,000
Total First Cost		$503,000,000
Federal Share of Cost (50%)		$251,500,000
Non-Federal Share of Cost (50%)		$251,500,000

Annual Charges

Federal Investment

Interest and Amortization (0.07131 x $251,500,000)	$ 17,934,000
Total Federal Annual Charge	$ 17,934,000

Non-Federal Investment

Interest and Amortization (0.07131 x 251,500,000) Breakwater Maintenance	$ 17,934,000
Breakwater Maintenance (14,000 tons @ $40.00 per ton)	560,000
Total Non-Federal Annual Charge	$ 18,494,000
Plan III: Total Annual Charge	$ 36,428,000

PLAN IV PRECAST CONCRETE SECTION / CONCRETE LEVELING SLAB/RUBBLE MOUND

Plan IV consists of a precast concrete section placed on a concrete leveling strip atop a rubble mound structure located along the base of the dune or bluff extending 100,000 feet parallel to the shore. A cross section of this structure is shown in Figure 2-5.

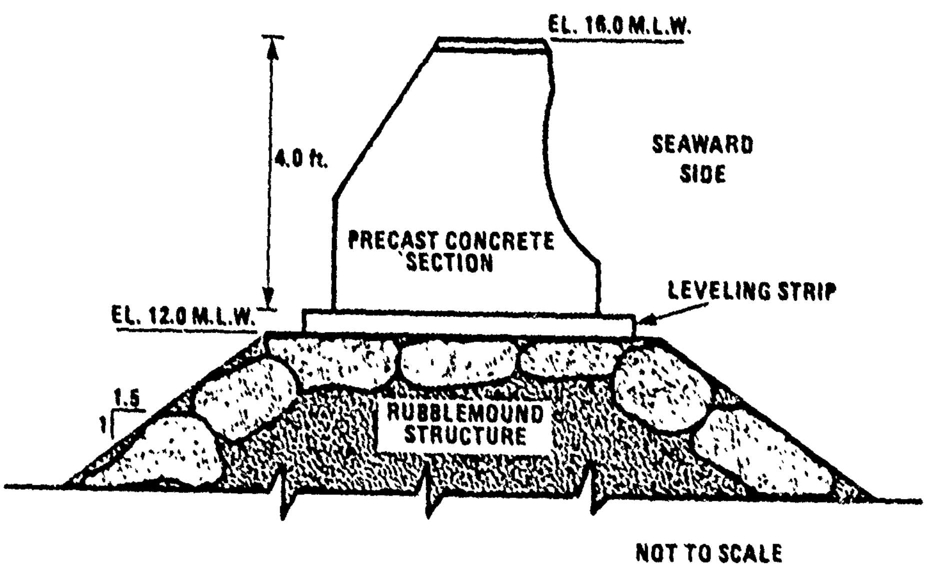


Figure 2-5. Plan IV - Precast Concrete Section/ Concrete Leveling Slab/Rubble Mound

ESTIMATED COSTS FOR PLAN IV - PRECAST CONCRETE SECTION/
CONCRETE LEVELING SLAB/RUBBLE MOUND

First Cost

Precast Concrete Barrier (@ $60.00/L.F.)		$ 6,000,000
Stone (1,600 tons @ 25.00/ton)		40,000,000
	Subtotal	46,000,000
Contingencies		9,200,000
	Subtotal	55,200,000
Engineering and Design		5,520,000
	Subtotal	60,720,000
Supervision and Administration		5,465,000
Total First Cost		$ 66,185,000
Federal Share of Cost (50%)		$ 33,092,500
Non-Federal Share of Cost (50%)		$ 33,092,500

Annual Charges

Federal Investment

Interest and Amortization (0.97131 x $33,092,500)	$ 2,360,000
Total Federal Annual Charge	$ 2,360,000

Non-Federal Investment

Interest and Amortization (0.07131 x $33,292,500)	$ 2,360,000
Concrete/Rubble Mound Maintenance (16,000 tons @ $40.00 per ton)	640,000
Total Non-Federal Annual Charge	$ 3,000,000
Plan IV: Total Annual Charge	$ 5,360,000

PLAN V STONE GROINS

A groin is designed to build a protective beach or retard erosion of an existing or restored beach by trapping littoral drift. Groins, which are usually constructed perpendicular to the shore, are employed to reduce the longshore transport out of an area by compartmenting the beach (U.S. Army Coastal Engineering Research Center, 1975).

Plan V consists of a system of 101 groins constructed of armor stone, spaced 1000 feet apart along 100,000 feet of shore and extending 245 feet seaward from the backshore (Figure 2-6).

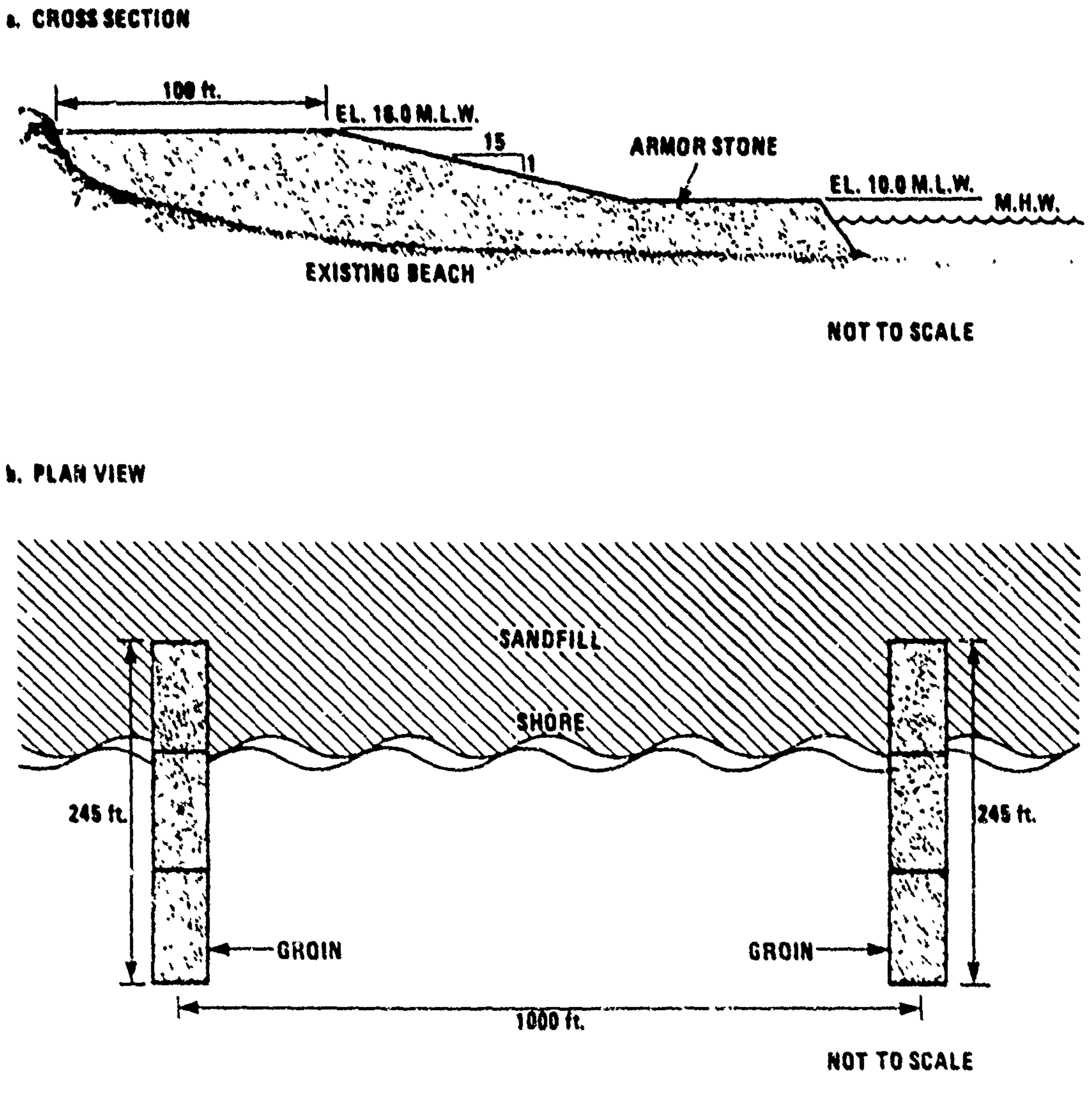


Figure 2-6. Plan V - Stone Groins

ESTIMATED COSTS FOR PLAN V - STONE GROINS

First Cost

Stone (737,000 tons @ $25.00/ton)		$ 18,425,000
Contingencies		2,685,000
	Subtotal	22,110,000
Engineering and Design		2,200,000
	Subtotal	24,310,000
Supervision and Administration		2,190,000
Total First Cost		$ 26,500,000
Federal Share of Cost (50%)		$ 13,250,000
Non-Federal Share of Cost (50%)		$ 13,250,000

Annual Charges

Federal Investment

Interest and Amortization (0.07131 x $13,250,000)	$ 945,000
Total Federal Annual Charge	$ 945,000

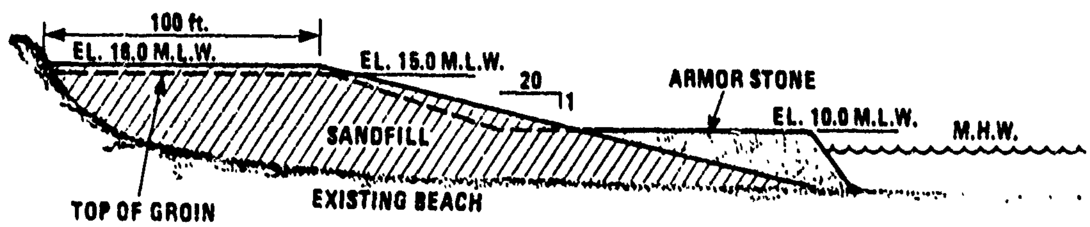
Non-Federal Investment

Interest and Amortization (0.07131 x $13,250,000)	$ 945,000
Groin Maintenance (7000 tons @ $40.00 per ton)	280,000
Total Non-Federal Annual Charge	$ 1,225,000
Plan V: Total Annual Charge	$ 2,170,000

PLAN VI STONE GROINS AND PLACED SANDFILL

Plan VI is a combination of Plan V (Stone Groins) and Plan VII (Placed Sandfill). It consists of a groin system with sandfill extending along 100,000 feet of beach with the groins extending 315 feet seaward from the backshore (Figure 2-7). The landward end of the groin would be covered by the sandfill to a minimum depth of 1 foot.

a. CROSS SECTION



NOT TO SCALE

b. PLAN VIEW

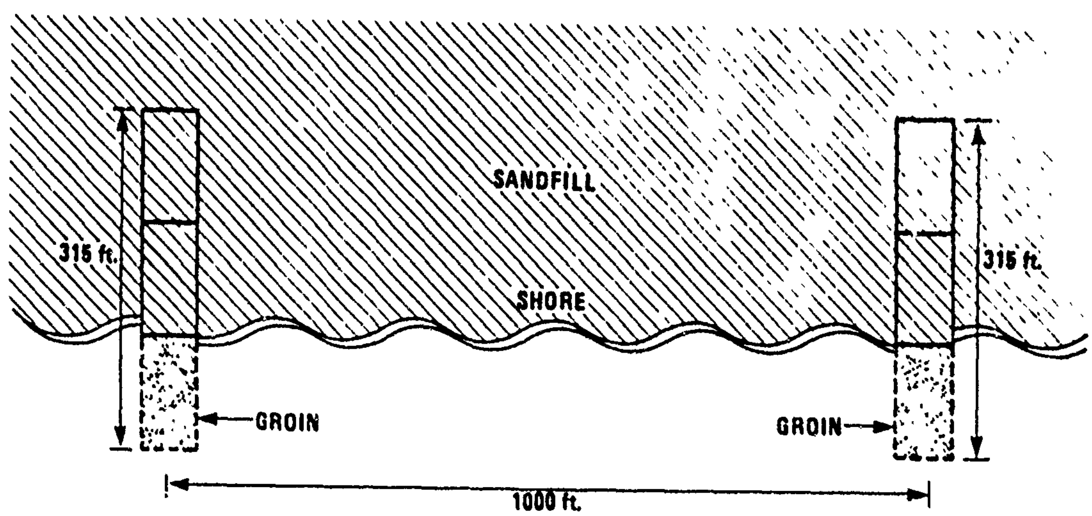


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Figure 2-7 Plan VI - Stone Groins and Placed Sandfill

ESTIMATED COSTS FOR PLAN VI - STONE GROINS AND PLACED SANDFILL

First Cost

Sand (8,360,000 cubic yards @ 5.00/c.y.)		$ 41,800,000
Stone (737,000 tons @ $25.00/ton)		18,425,000
	Subtotal	60,225,000
Contingencies		12,000,000
	Subtotal	72,225,000
Engineering and Design		7,225,000
	Subtotal	79,450,000
Supervision and Administration		7,150,000
Total First Cost		$ 86,600,000
Federal Share of Cost (50%)		$ 43,300,000
Non-Federal Share of Cost (50%)		$ 43,300,000

Annual Charges

Federal Investment

Interest and Amortization (0.97131 x $ 43,300,000)	$ 3,088,000
Periodic Nourishment (21,000 cubic yards @ $ 6.00 per cubic yard)	126,000
Total Federal Annual Charge	$ 3,214,000

Non-Federal Investment

Interest and Amortization (0.07131 x $ 43,300,000)	$ 3,088,000
Periodic Nourishment (21,000 cubic yards @ $ 6.00 per cubic yard)	126,000
Groin Maintenance (7,000 tons @ $40.00 per ton)	280,000
Total Non-Federal Annual Charge	$ 3,494,000
Plan VI: Total Annual Charge	$ 6,708,000

( ) PLAN VII PLACED SANDFILL ONLY

Plan VII consists of placement of sandfill along approximately 100,000 feet of shore front, which would provide a 100-foot berm. The beach would slope seaward on a 20 horizontal to 1 vertical slope.

The sandfill would form a protective beach that can dissipate wave energy. This method of shore protection may benefit rather than harm the downdrift shores as well as provide a valuable recreational area [U.S. Army Coastal Engineering Research Center (CERC), 1975]. However, maintaining a protective beach in a high-energy wave environment without the aid of structures can be costly.

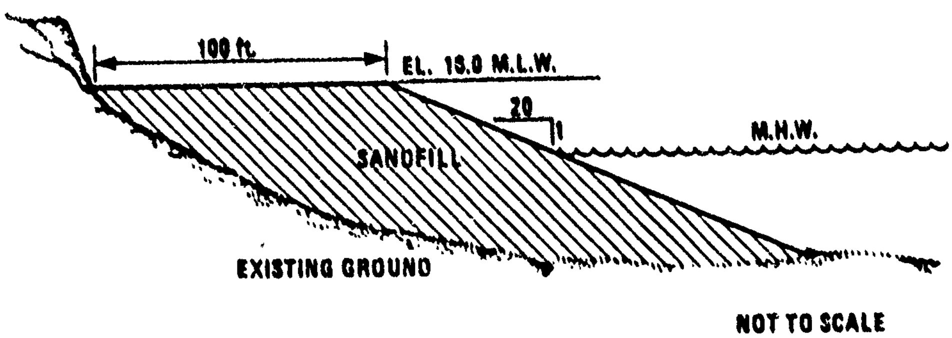

Figure 2-8. Plan VII - Placed Sandfill Only

ESTIMATED COSTS FOR PLAN VII - PLACED SANDFILL ONLY

First Cost		
Sand (8,360,000 cubic yards @ $5.00/c.y.)		$ 41,800,000
Contingencies		8,360,000
	Subtotal	50,160,000
Engineering and Design		5,020,000
	Subtotal	55,180,000
Supervision and Administration		4,960,000
Total First Cost		$ 60,140,000
Federal Share of Cost (50%)		$ 30,070,000
Non-Federal Share of Cost (50%)		$ 30,070,000
Annual Charges		
Federal Investment		
Interest and Amortization		
(0.07131 x 30,070,000)		$ 2,144,000
Periodic Nourishment (42,000 cubic yards @ $ 6.00 per cubic yard)		252,000
Total Federal Annual Charge		$ 2,396,000
Non-Federal Investment		
Interest and Amortization (0.07131 x $ 30,000,000)		$ 2,144,000
Periodic Nourishment (42,000 cubic yards @ $6.00 per cubic yard)		252,000
Total Non-Federal Annual Charge		$ 2,396,000
Plan VII: Total Annual Charge		$ 4,792,000

PLAN VIII DUNE RESTORATION

This plan consists of sandfill and dune grass planting for stabilization. As shown in Figure 2-9, the dune dimensions would be similar to existing dunes. This plan is applicable to those areas where the backshore is barren or where incipient or established dunes exist. State and local government and private interests would be responsible for funding this project.

Dune restoration experiments involving sand fencing and beach grass plantings have been successful on Cape Cod (in Appendix 1, see "Inhibiting Erosion"). These and other experiments have resulted in guidelines for dune creation and stabilization (Knutson, 1977).

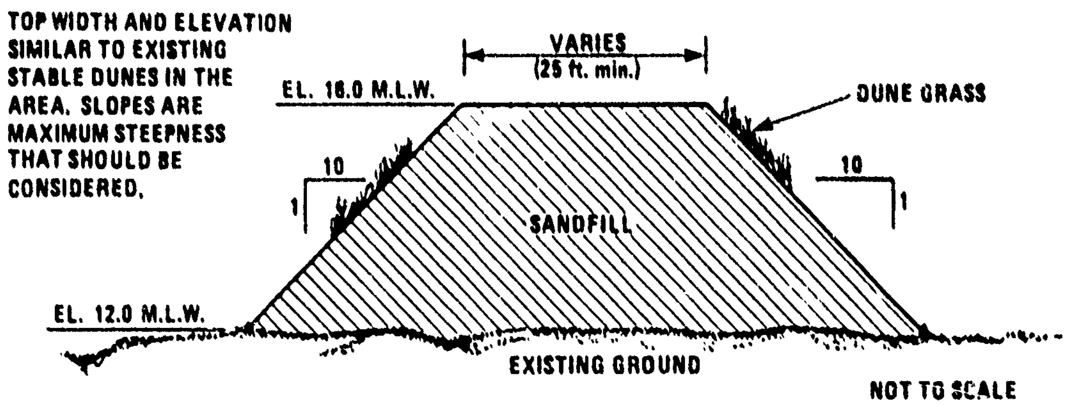

Figure 2-9. Plan VIII - Dune Restoration

ESTIMATED COSTS FOR PLAN VIII - DUNE RESTORATION

First Cost

Sand (661,000 cubic yards)		$ 3,305,000
Grass and Fertilizer (804,00 sq. yd. @ $0.50/sq.yd.)		400,000
	Subtotal	3,705,000
Contingencies		740,000
	Subtotal	4,445,000
Engineering and Design		445,000
	Subtotal	4,890,000
Supervision and Administration		440,000
Total First Cost		$ 5,330,000

Annual Charges

Non-Federal Investment

Interest and Amortization (5,334,000 x $ 0.07131)	$ 381,000
Periodic Nourishment (100,000 cubic yards @ $6.00 per cubic yard)	600,000
Plan VIII: Total Annual Charge	$ 981,000

Table 2-1 sumarizes the initial costs and annual charges for the eight plans described in this appendix. Design features of each and the limits of the area covered are shown in Plate 2-1. A discussion of the benefits and a benfit-cost analysis are presented in Appendix 3.

Table 2-1. Summary of First Cost and Annual Charges

PLAN NO.	TYPE OF PROTECTION	FIRST COST (millions)	ANNUAL CHARGES	
			FEDERAL (millions)	NON-FEDERAL (millions)
I	Rock Revetment	$ 35.97	$ 1.283	$ 1.683
II	Nearshore Stone Mound	147.00	5.241	6.841
III	Offshore Stone Breakwater	503.00	17.934	18.494
IV	Precast Concrete Section/Concrete Leveling Slab/ Rubble Mound	66.18	2.360	3.000
V	Stone Groins	26.50	0.945	1.225
VI	Stone Groins and Placed Sandfill	86.60	3.214	3.494
VII	Placed Sandfill Only	60.14	2.396	2.396
VIII	Dune Restoration (Sandfill and Beach Grass Planting)	5.33	--	0.981

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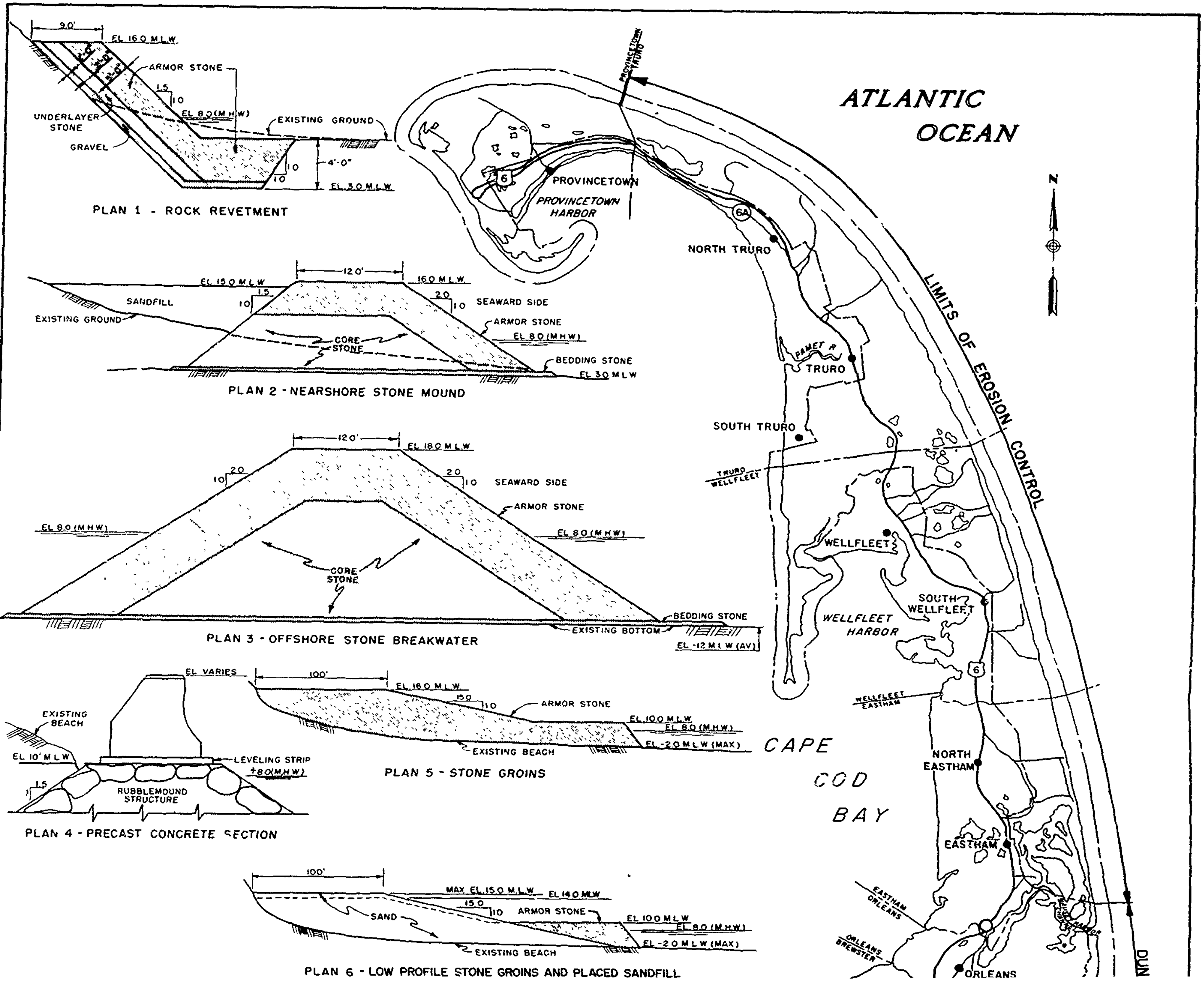
ATLANTIC OCEAN
LIMITS OF EROSION CONTROL
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WELLFLEET
WELLFLEET
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EASTHAM
NORTH EASTHAM
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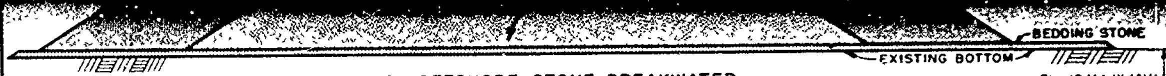
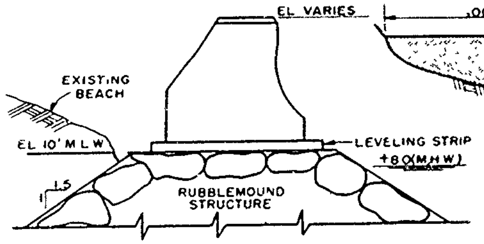
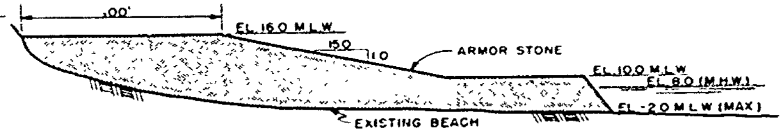
ORLEANS
ORLEANS
BREWSTER
ORLEANS
DUN
CAPE COD BAY
9.0'
EL 16.0 M.L.W.
ARMOR STONE
1.5
1.0
EL 8.0 (M.H.W.)
UNDERLAYER STONE
GRAVEL
EXISTING GROUND
4'-0"
EL 3.0 M.L.W.
PLAN 1 - ROCK REVETMENT
12.0'
EL 15.0 M.L.W.
16.0 M.L.W.
SANDFILL
2.0
SEAWARD SIDE
EXISTING GROUND
ARMOR STONE
EL 8.0 (M.H.W.)
CORE STONE
BEDDING STONE
EL 3.0 M.L.W.
PLAN 2 - NEARSHORE STONE MOUND
12.0'
EL 18.0 M.L.W.
SEAWARD SIDE
ARMOR STONE
EL 8.0 (M.H.W.)
CORE STONE
BEDDING STONE
EXISTING BOTTOM
EL -12 M.L.W. (AV.)
PLAN 3 - OFFSHORE STONE BREAKWATER
EL VARIES
EXISTING BEACH
EL 10' M.L.W.
LEVELING STRIP
+8.0 (M.H.W.)
RUBBLEMOUND STRUCTURE
PLAN 4 - PRECAST CONCRETE SECTION
100'
EL 16.0 M.L.W.
15.0
ARMOR STONE
EL 10.0 M.L.W.
EL 8.0 (M.H.W.)
EL -2.0 M.L.W. (MAX)
EXISTING BEACH
PLAN 5 - STONE GROINS
100'
MAX EL 15.0 M.L.W.
EL 14.0 M.L.W.
15.0
ARMOR STONE
SAND
EL 10.0 M.L.W.
EL 8.0 (M.H.W.)
EL -2.0 M.L.W. (MAX)
EXISTING BEACH
PLAN 6 - LOW PROFILE STONE GROINS AND PLACED SANDFILL



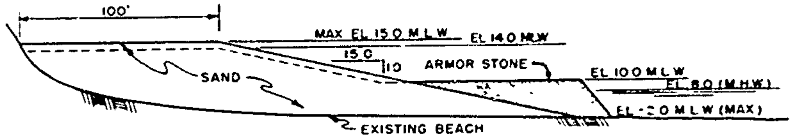
PLAN 3 - OFFSHORE STONE BREAKWATER



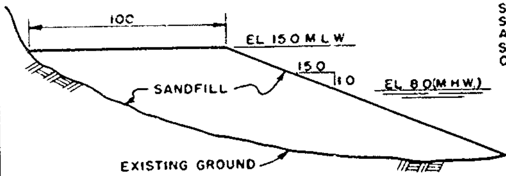
PLAN 4 - PRECAST CONCRETE SECTION



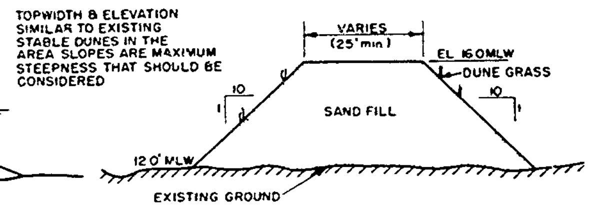
PLAN 5 - STONE GROINS



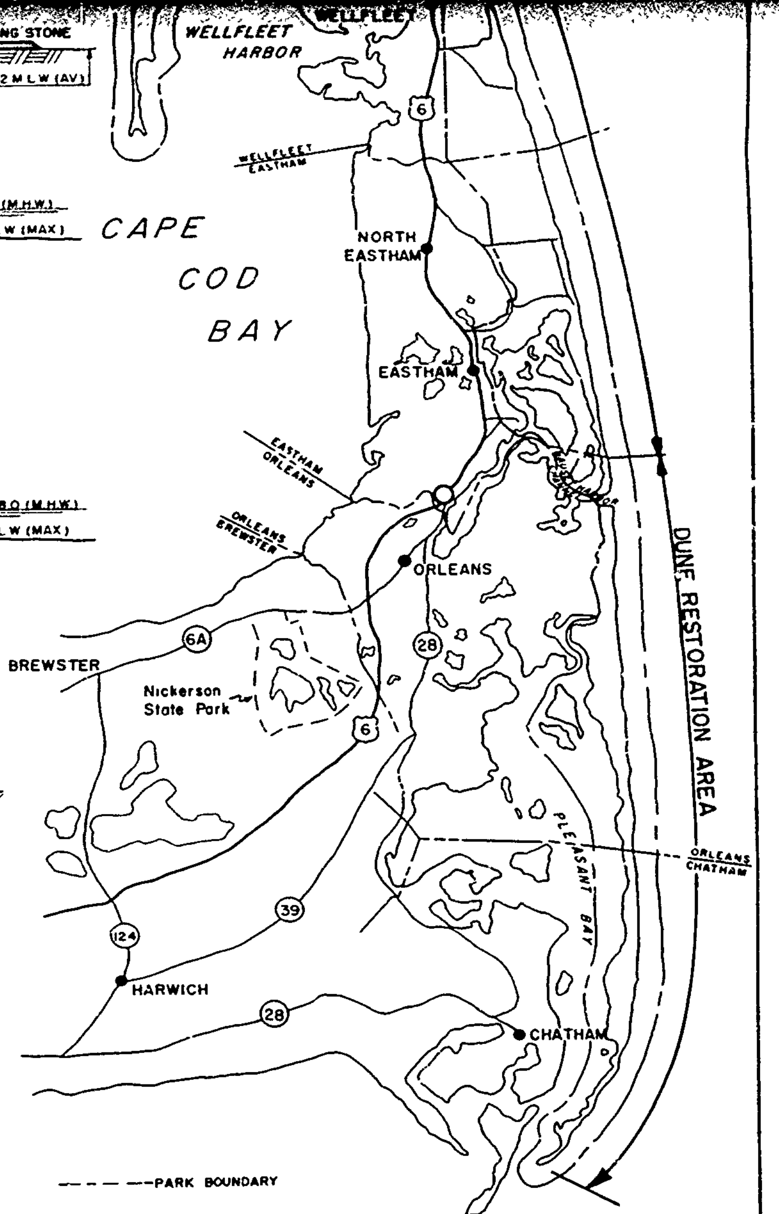
PLAN 6 - LOW PROFILE STONE GROINS AND PLACED SANDFILL



PLAN 7 - PLACED SANDFILL ONLY



PLAN 8 - DUNE RESTORATION



METHODS OF EROSION CONTROL

NOT TO SCALE

NOTES

1 PLAN 1 ROCK REVETMENT AT AN AVERAGE BOTTOM ELEVATION OF 3 0 FEET ABOVE MEAN LOW WATER AND A TOP ELEVATION OF 16 0 FEET ABOVE MEAN LOW WATER

2 PLAN 2 NEARSHORE STONE MOUND LOCATED APPROXIMATELY 150 FEET SEAWARD OF THE BASE OF DUNE OR BLUFF CONSTRUCTED TO AN AVERAGE DEPTH OF 3 FEET ABOVE MEAN LOW WATER AND A TOP ELEVATION OF 16 FEET ABOVE MEAN LOW WATER

3 PLAN 3 OFFSHORE STONE BREAKWATER APPROXIMATELY 1200 FEET OFFSHORE ALONG THE LIMITS OF IMPROVEMENT TOP ELEVATION IS ABOUT 18 0 FEET ABOVE MEAN LOW WATER WITH AN AVERAGE BOTTOM ELEVATION OF 12 0 FEET BELOW MEAN LOW WATER

4 PLAN 4 PRECAST CONCRETE SECTION 4 FEET HIGH ON A LEVELING STRIP ATOP A RUBBLEMOUND STRUCTURE LOCATED ALONG THE BASE OF DUNE OR BLUFF AND PARALLEL TO THE SHORE

5 PLAN 5 A SYSTEM OF STONE GROINS SPACED 1000 FEET ON CENTER

6 PLAN 6 SANDFILL AND GROINS A SYSTEM OF GROINS SPACED 1000 FEET ON CENTER INCLUDING PLACEMENT OF SUITABLE SANDFILL BETWEEN THE GROINS

7 PLAN 7 PLACEMENT OF SUITABLE SANDFILL ALONG THE SHOREFRONT THIS WOULD PROVIDE A LEVEL 100 FOOT BEACH BERM AT ELEVATION 15 0 FEET ABOVE MEAN LOW WATER AND A DRY BEACH WIDTH OF ABOUT 240 FEET ABOVE MEAN HIGH WATER

8 PLAN 8 DUNE RESTORATION CONSISTING OF SANDFILL AND DUNE GRASS PLANTING FOR STABILIZATION DIMENSIONS WOULD BE SIMILAR TO EXISTING DUNES IN THE AREA

9 TIDAL RANGES IN THE STUDY AREA VARY FROM 7 8 FEET ABOVE MEAN LOW WATER ON THE OUTSIDE SHORE OF CHATHAM TO 10 6 FEET ABOVE MEAN LOW WATER AT PROVINCETOWN FOR PLANS 1 8 ABOVE AN AVERAGE TIDE OF 8 0 FEET ABOVE MEAN LOW WATER WILL BE USED

10 THE PROJECT AREA FOR PLANS 1 THRU 7 EXTENDS FOR APPROXIMATELY 20 MILES NORTH FROM THE EASTHAM ORLEANS TOWN LINE PLAN 8 IS TO BE USED FOR LOW LYING AREAS SUCH AS NAUSET BEACH OR WHERE SUCH PROBLEMS AS OVERTOPPING OCCUR

BEACH EROSION CONTROL STUDY

CAPE COD EASTERLY SHORES

CAPE COD, MASSACHUSETTS

PLANS OF IMPROVEMENTS

SCALE IN MILES

1 1/2 0 1 2 3

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS

PLATE 2

APPENDIX 3

ESTIMATES OF BENEFITS AND ASSESSMENT OF SOCIAL AND ECONOMIC EFFECTS FROM IMPROVEMENTS

PREPARED BY THE NEW ENGLAND DIVISION
CORPS OF ENGINEERS
DEPARTMENT OF THE ARMY

ESTIMATES OF BENEFITS AND ASSESSMENT OF SOCIAL AND ECONOMIC EFFECTS FROM IMPROVEMENTS

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ECONOMIC AND SOCIAL CONSIDERATIONS

INTRODUCTION

This appendix addresses economic and social considerations and impacts associated with beach erosion control of Cape Cod's easterly shores. It also presents an overview of the study area in terms of its population, land use characteristics and economy. Detailed information for the individual towns can be found in Section F of Appendix 1, "Land Use on Outer Cape Cod."

ECONOMIC BACKGROUND

Population Trends

The population of Cape Cod, or Barnstable County, has grown rapidly in the past 25 years; from 1950 to 1976, the year-round population increased 175 percent. During this same period the total population of the U.S. increased by only 34 percent. The Commonwealth of Massachusetts and the New England region experienced lower population gains during this period, 21 percent and 27 percent, respectively. Growth trends are summarized in Table 3-1. Growth information for the individual towns can be found in Section F of Appendix 1, "Land Use on Outer Cape Cod."

Data compiled by the Cape Cod Planning and Economic Development Commission (CCPEDC), indicate that in-migration (the net increase in population due to an excess of people moving in over people moving out) has accounted for over 90 percent of the total population growth in Barnstable County from 1965 to 1970. (See Table 3-2.) The in-migration trend reflects in part the growing attraction of Cape Cod for people seeking a place to retire; it also reflects the Cape's attraction as a place to live for people who hold jobs outside Barnstable County as far north as Boston.

The composition by age group of Cape Cod's population has changed between 1940 and 1970 (Tables 3-3 and 3-4). The 65-and-over age group grew the fastest, 28 percent of the increase between 1960 and 1970. This group increased from 13 percent of the total population in 1960 to 17 percent in 1970. In the 5 years from 1970 to 1975, the number of residents over 65 grew by nearly 50 percent compared to 6 percent statewide. The CCPEDC estimates that about 25 percent of the Cape's year-round residents are now senior citizens.

Table 3-1. Population Growth, 1950-1970

YEAR	UNITED STATES (million)	NEW ENGLAND (million)	MASSACHUSETTS (million)	BARNSTABLE COUNTY (thousand)
1950	152.3	9.3	4.7	45.8
1960	180.0	10.5	5.2	70.3
1970	203.7	11.8	5.7	96.7
PERCENT INCREASE:				
1950-1960	18.2	12.9	10.6	50.2
1960-1970	13.2	12.4	9.6	37.6
1950-1970	33.7	26.9	21.3	106.6

Table 3-2. Natural Population Increase versus In-Migration on Cape Cod, 1966-1970

	PERCENT OF TOTAL POPULATION INCREASE	
YEAR	NATURAL	IN-MIGRATION
1966	5.9	94.1
1967	14.1	85.9
1968	3.0	97.0
1969	9.9	90.1
1970	1.5	98.5
Total 1966-1970	6.9	93.1

Source: Cape Cod Planning and Economic Development Commission

Table 3-3. Contributions to Cape Cod's Population Growth by Age Group, 1940-1970

AGE GROUP	PERCENT OF TOTAL POPULATION INCREASE		
	1940-1950	1950-1960	1960-1970
Under 5	22.3	15.7	-4.9
5-19	5.8	29.5	34.0
20-44	38.2	25.5	15.1
45-64	20.3	15.4	27.8
65 and over	13.4	13.9	28.0
Total	100.0	100.0	100.0

Table 3-4. Distribution of Cape Cod's Resident Population by Age Group, 1940-1970

AGE GROUP	PERCENT OF TOTAL POPULATION			
	1940	1950	1960	1970
Under 5	7.0	10.1	12.0	7.4
5-19	24.5	20.7	23.7	26.5
20-44	34.5	35.2	31.9	27.3
45-64	22.2	21.8	19.7	21.9
65 and over	11.8	12.2	12.7	16.9
Total	100.0	100.0	100.0	100.0

The 45-to-64 age group followed closely behind the 65-and-over age group, accounting fro over 27 percent of the increase in the county's total population between 1960 and 1970. This age group makes up 22 percent of the totoal population.

The younger age groups (5-19, 20-44) accounted for approximately 49 percent of the Cape's population increase during the 1960 to 1970 time period. The under-5 age group decreased from 1960 to 1970.

The composition of Cape Cod's resident population (based on Table 3-4) is presented graphically in Figures 3-1 and 3-2. The noitceable shift in the population profile that occurred from 1960 to 1970 indicates a trend that should be monitored in th future: the decreasing percentage in the under-5 group, a steady 20-year decline of the percentage in the 20-to-44 age group (those who would be the parents of young children), and the increase in the over-65 age group.

The impact of seasonal populations on the area's economy, future development, facilities and services is significant as detailed in Section F of Appendix 1, "Land Use on Outer Cape Cod." The six towns annually experience summer population increases that range from 2.5 to 9 times their year-round populations.

Land Use

The central role of tourism has shaped much of the present land use and will continue to influence development in the future. Land use also reflects the economic and population characteristics of Cape Cod. In 1971 about 80 percent of the Cape was covered by agricultural or open lands, forest or wetlands. Residential housing accounted for another 14 percent of the area, outdoor recreation for 2 percent, and industrial-commercial, open public and mining/waste disposal for about 1 percent each. The Cape was even less developed in 1951 when only 5 percent of the land area was residential and 93 percent was forest, agricultural or wetlands.

The change in residential area during the 20-year period between 1951 and 1971 reflects the increase in population, both seasonal and year-round, living in Barnstable County. Open and agricultural land has been taken over primarily by housing developments, and the decrease in farming has allowed abandoned fields and pastures to revert to young forests of scrub oak and pitch pine.

In general, the land use pattern in the easterly shore communities is characterized by village centers of commercial and residential uses, with residences scattered throughout the remainder of the town.

The major preservation factor on the outer Cape has been acquisition of land for the Cape Cod National Seashore. This has provided all the towns of the outer Cape with a federally designated area to be preserved for the use of all, with no further commercial or residential development. The boundaries of the Seashore include 16 percent of the land in Barstable County, 60 percent of which is on the outer Cape. Over half of the town land of

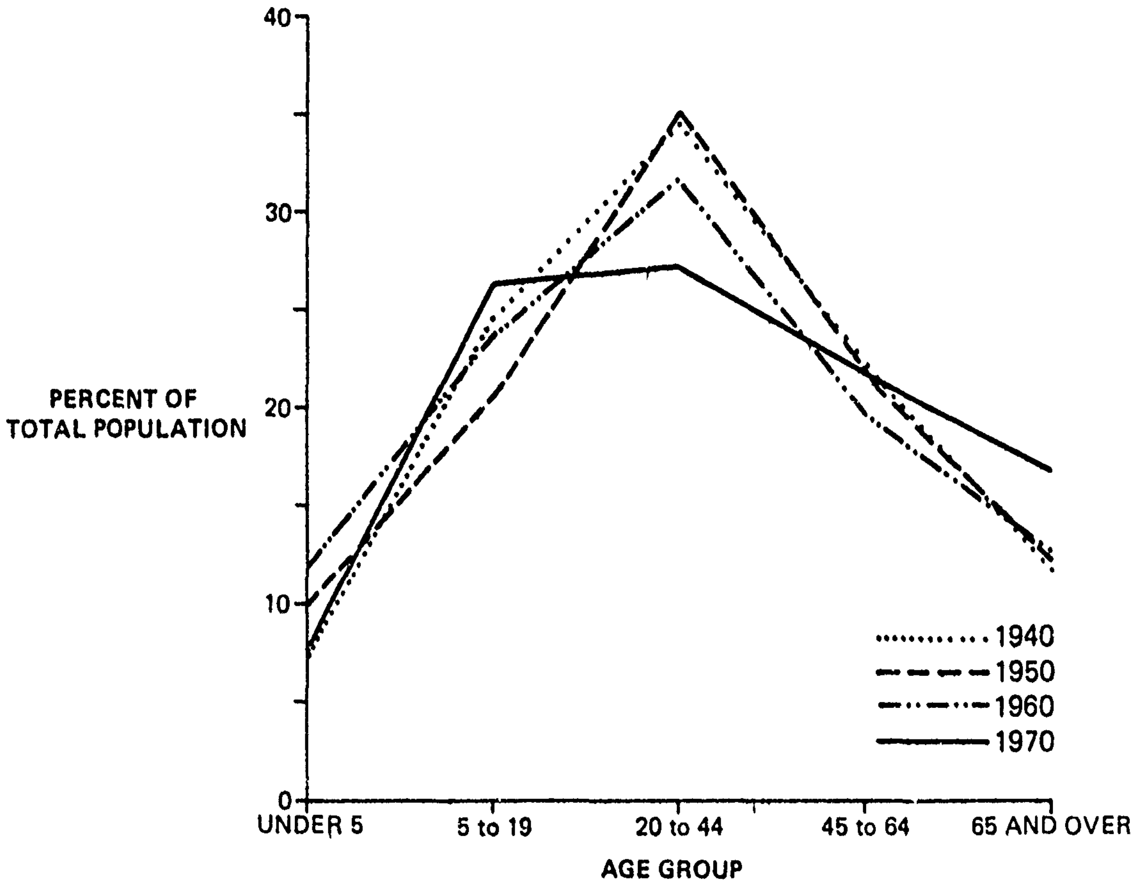

Figure 3-1. Distribution of Cape Cod's Resident Population by Age Group, 1940-1970

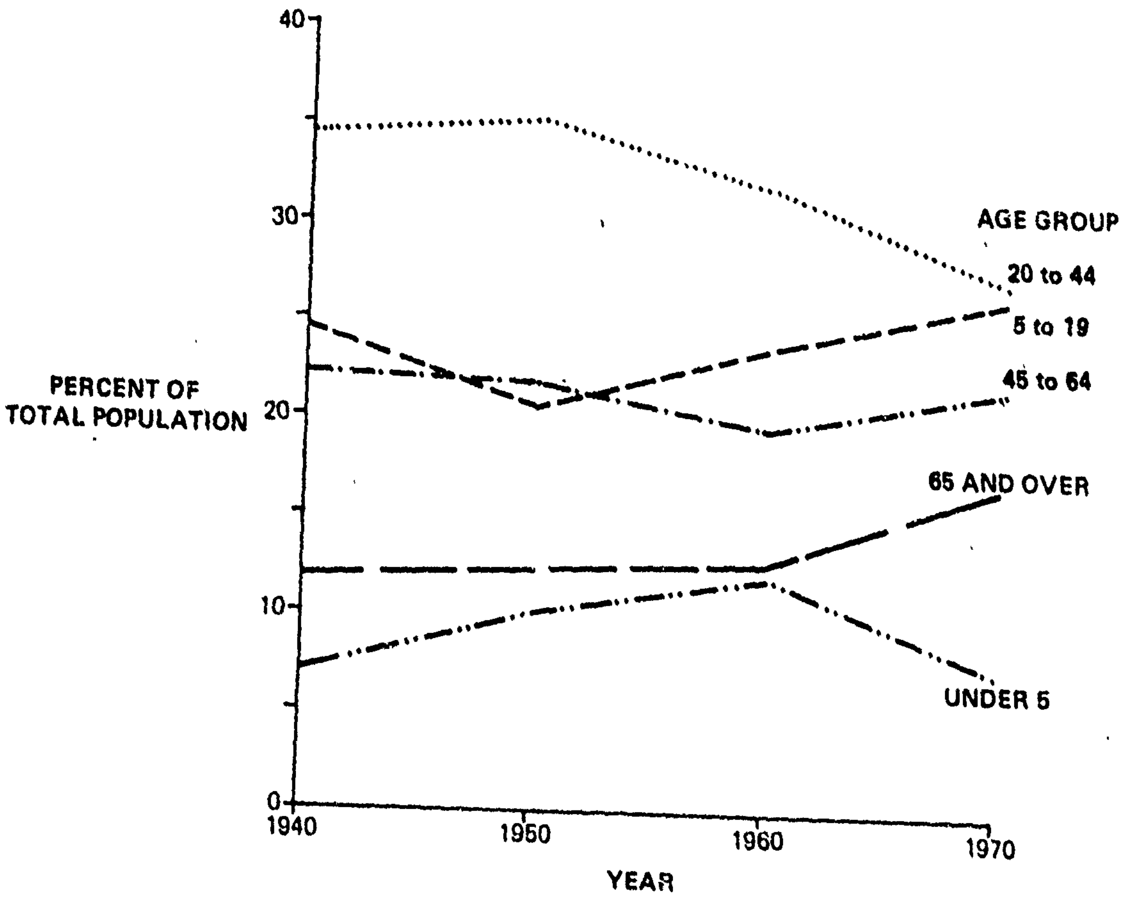

Figure 3-2. Chronological Distribution of Cape Cod's Resident Population by Age Group, 1940-1970

Provincetown, Truro and Wellfleet is included within the Seashore boundaries. Approximately 20 to 40 percent of each of the communities of Eastham, Orleans and Chatham is also within Seashore bounds.

The Economy

Cape Cod is endowed with unique locational, climatic, and aesthetic advantages that support the resort industry and provide a pleasant atmosphere for retirement. In order to provide an overview of the Cape Cod economy in general and of the six outer Cape towns in particular, the following economic measures were examined: personal income, per capita income, source of income, employment by industry and unemployment.

Personal Income - Total personal income for Cape Cod (Barnstable County), which is defined as current income received by area residents from all sources, rose by 390 percent from 1950 to 1970. This increase outstripped gains in the United States (253 percent), New England (241 percent), and Massachusetts (225 percent). However, the Cape Cod experience is explained in large part by the more than doubling of its resident population over the period. Comparative population movements in the Nation, New England region, and State were 34 percent, 27 percent and 21 percent, respectively.

Per Capita Income - Growth in per capita income on the Cape (personal income divided by the total area resident population) gives a different picture with respect to the Nation, region, and State. Per capita income on the entire Cape grew 122 percent from 1950 to 1970, but lagged behind the nation (162 percent), New England and Massachusetts (both 167 percent) in magnitude of gain. Here, as in personal income, population gains have affected the estimates. Per capita income growth may have been lower on the Cape because increased immigration caused total personal income to be distributed among more people. It is important to note that five of the six towns on the outer Cape rank above the state and county in levels of per capita income (Table 3-5).

Sources of Income - Major sources of total personal income for Cape Cod are displayed in Table 3-6. Historical developments in the local economy evident from this data are: (1) wage and salary payments have remained a relatively stable portion of personal income over the period, and (2) transfer payments, reflecting primarily social security benefits and pensions, have accounted for a steadily increasing portion of total personal income. As of 1972 transfer payments had risen to 17.2 percent of total personal income on Cape Cod, thus doubling in 22 years and illustrating the increased immigration of retirees and people over 65 years of age.

Major Employing Industries - Because Cape Cod and the six outer Cape towns are characterized by a seasonal tourist-vacation economy and an increasing over-65 age group, most jobs are in the trade and service industries. Major employing industries in the easterly shore towns are discussed in Section F of Appendix 1, "Land Use on Outer Cape Cod."

Unemployment - The seasonal character of the Cape Cod economy and the concentration of jobs in the trade and service industries cause unemployment problems. Table 3-7 compares the six project area towns, Barnstable County and Massachusetts on an annual average basis for 1977. The labor force statistics for the six towns should be interpreted with caution for the following reasons: (1) total labor force for the six towns is less than 20 percent of the Barnstable County total; and (2) while State and county labor force estimates are calculated independently, town data are shared out of total area labor estimates based on ratios from the 1970 Census. The seasonal character of the Cape Cod economy is evident in the comparison of February and August 1977 unemployment rates shown in Table 3-8.

BENEFIT ANALYSIS

INTRODUCTION

The study area consists of forty-six miles of shoreline from Long Point in Provincetown to the southern end of Nauset Beach on the Chatham spit. A 20-mile stretch of this shoreline from just south of the Provincetown-Truro line to south of Nauset Light has been selected for structural plans of improvement. This area encompasses most of the outer Cape cliffs where erosion has been most pronounced. North of the considered area the shore is characterized by accretion making protective structures unnecessary. Migrating spits are typical of the area south of the plan limit making the effects of protective structures unpredictable. The structural plans of improvement are:

Plan I	Rock Revetment
Plan II	Nearshore Stone Mound
Plan III	Offshore Stone Breakwater
Plan IV	Precast Concrete Section/Concrete Leveling Slab/Rubble Mound
Plan V	Stone Groins
Plan VI	Stone Groins and Placed Sandfill
Plan VII	Placed Sandfill Only
Plan VIII	Dune Restoration, Planting Dune Grass, etc.

Plans I through VII apply to the aforementioned 20-mile stretch of shoreline, while Plan VIII is applicable to the entire 46-mile study area. A description of each of these plans is contained in Appendix 2, along with a statement of costs. Annual costs of each alternative to be used in benfit/cost computations are as follows:

Table 3-5. Per Capita Income for Outer Cape Cod, 1969 and 1974

TOWNSHIP	PER CAPITA INCOME ($) 1969	1974	PERCENT CHANGE 1969-1974	1974 RANK IN MASSACHUSETTS OUT OF 351 CITIES AND TOWNS
Provincetown	2,680	3,706	38.3	309
Truro	3,694	5,180	40.2	77
Wellfleet	3,708	5,363	44.6	59
Eastham	3,808	5,317	39.6	63
Orleans	4,761	6,666	40.0	23
Chatham	3,737	5,412	44.8	52
Barnstable County	3,353	4,779	42.5	-
Massachusetts	3,407	4,755	39.6	-

Source: U.S. Department of Commerce, Bureau of the Census

Table 3-6. Relative Shifts in Major Sources of Personal Income, Cape Cod, 1950-1969

SOURCE	PERCENT OF ADJUSTED TOTAL PERSONAL INCOME			
	1950	1959	1965	1969
Wage and salary disbursements	56.9	60.0	59.4	56.6
Other labor income	0.8	1.4	1.7	2.0
Proprietor's income	19.8	13.2	11.5	9.6
Property income	14.0	16.1	17.2	17.7
Transfer payments	8.5	9.3	10.2	14.1
Adjusted total personal income	100.0	100.0	100.0	100.0

Source: U.S. Department of Commerce, Office of Business Economics, Regional Economics Information System

Table 3-7. Labor Force Summary, 1977

TOWNSHIP	LABOR FORCE	EMPLOYMENT	UNEMPLOYMENT	UNEMPLOYMENT RATE (percent)
Provincetown	2,515	1,684	831	33.0
Truro	474	448	26	5.5
Wellfleet	1,164	984	180	15.5
Eastham	1,145	1,071	74	6.5
Orleans	2,208	1,869	339	15.4
Chatham	2,924	2,733	191	6.5
Barnstable County	60,900	54,000	6,900	11.3
Massachusetts	2,779,600	2,554,600	225,300	8.1

Source: Massachusetts Division of Employment Security

Table 3-8. Unemployment Rates, 1977

TOWNSHIP	FEBRUARY 1977	AUGUST 1977
Provincetown	45.6	26.5
Truro	9.2	4.2
Wellfleet	23.7	11.8
Eastham	10.5	4.8
Orleans	23.5	11.7
Chatham	10.6	4.9
Barnstable County	17.9	8.5
Massachusetts	7.6	5.9

Source: Massachusetts Division of Employment Security

Table 3-9. Summary of First Cost and Annual Charges

PLAN NO.	TYPE OF PROTECTION	FIRST COST (millions)	ANNUAL CHARGES FEDERAL (millions)	ANNUAL CHARGES NON-FEDERAL (millions)
I	Rock Revetment	35.97	1.283	1.683
II	Nearshore Stone Mound	147.00	5.241	6.841
III	Offshore Stone Breakwater	503.00	17.934	18.494
IV	Precast Concrete Section/Concrete Leveling Slab/ Rubble Mound	66.18	2.360	3.000
V	Stone Groins	26.50	0.945	1.225
VI	Stone Groins and Placed Sandfill	86.60	3.214	3.494
VII	Placed Sandfill Only	60.14	2.396	2.396
VIII	Dune Restoration (Sandfill and Beach Grass Planting)	5.33	-	0.981

The ultimate goal of each improvement (except dune stabilization, Plan VIII) is to prevent further erosion of the cliffs behind the beach. This can be accomplished by protecting the cliffs, themselves or by protecting the beaches in front of the cliffs. Protection of the beach would result in protection of the cliffs since a stable beach full of sand would reduce the impact of wave action on the base of the cliff. Cliffs are vulnerable to erosion when the waves draw out and destroy the base, causing the cliff to collapse. Three of the plans of improvement, however, might involve loss of the beaches as they exist today. These plans are Plan I, Rock Revetment; Plan II, Nearshore Stone Mound; and Plan IV, Concrete Section/ Slab/Rubble Mound.

Within the 20-mile structural project area lie twelve beaches which are open to the public; five are under the jurisdiction of the National Park Service as parts of the Cape Cod National Seashore and the remainder are town beaches belonging to either Truro or Wellfleet. The twelve beaches, by town, are:

TRURO:	Head of the Meadow, National Park Service Head of the Meadow, Town of Truro Highland Beach, National Park Service Longnook Beach, Town of Truro Ballston Beach, Town of Truro
WELLFLEET:	Newcomb Hollow, Town of Wellfleet Cahoon Hollow, Town of Wellfleet White Crest, Town of Wellfleet Le Count Hollow, Town of Wellfleet Marconi Beach, National Park Service
EASTHAM:	Nauset Light Beach, National Park Service Coast Guard Beach, National Park Service

One of the most important attractions that Cape Cod has to offer is its natural resources. Stretches of natural beach, quiet coves and snug harbors make it Massachusetts' most popular recreational area and attract thousands of summer vacationers yearly. The 20-mile project area for structural alternatives is an uninterrupted stretch of natural beach backed by sand dunes, bluffs and scarps of various heights.

In the following discussion of project area beaches and the structural alternatives offered for controlling erosion, it must be remembered that the primary requirement for economic justification in Corps of Engineers civil works projects is that "the benefits to whomsoever they may accrue must be in excess of the estimated cost." Under the existing regulations and authorities (EM 1120-2-108) covering Corps beach erosion control projects, benefits can accrue to a project based on any or all of the five following categories: (1) physical damages prevented, (2) emergency and business costs avoided, (3) enhancement of property values, (4) increased recreational usage and (5) incidental benefits. Due to the fact that there are no commercial or industrial development and few residences located along the project area seashore, the only physical damages to be prevented would be to lands, a small number of houses, roads, parking lots, lighthouses and other existing beach facilities and structures that would be lost to erosion over the 50-year period of analysis under the 'without' project condition. In addition, the National Park Service does not permit any building or development within the Cape Cod National Seashore with the exception of visitor-oriented facilities. Since the Cape Cod National Seashore and town beaches in the study area are devoted solely to recreation, this benefit category will also be examined. The benefit analysis therefore will proceed by examining the lands and existing physical structures expected to be lost to erosion over the next fifty years and the recreational beach space supply/demand relationship. The benefits to each structural alternative would be (1) the dollar value of physical losses prevented and (2) the increased supply of recreational space supplied by the project.

It is estimated that the bluffs along the 20-mile structural alternatives project area have been eroding at an average rate of three to five feet per year with greater losses occurring during severe storms and at times

of exceptionally high tides, (e.g. storm of February 1978). There is evidence that accretion of sand is occurring north of the 20-mile project area on the Provincetown coast. South of the project area along the Chatham spit and Nauset Beach some buildup is occurring from the loss of material in the project area, but the gain/loss process along the Nauset Beach and Chatham spit area is so dynamic that an annual loss figure is too difficult to ascertain. In the project area itself, an average figure of 3 to 5 feet per year for the 50-year life of the project was used to measure the extent of erosion. In very rough terms this equals 21,120,000 square feet of land lost to erosion in 50 years or approximately 485 acres. Erosion is not occurring at this constant rate for the entire 20 miles; it is more severe in some locations (Highland and Nauset Light beaches) and less severe in others; however, for study purposes 3 to 5 feet per year is an appropriate measure.

Analysis

Physical Damages Prevented

In order to ascertain the value of damages prevented by the structural alternatives in the project area, an estimate of land and buldings to be lost to erosion must be made. As mentioned previously, shoreland consisting of dunes and bluffs amounting to approximately 485 acres would be lost over the 50-year period in the absence of the project. Since nearly all of this shorefront land is owned by the National Park Service and the towns of Truro, Wellfleet and Eastham and is set aside and used solely for recreation, it is difficult to attach a value to the land.

Although this land is out of circulation and does not have its selling price determined by the usual market forces of demand and supply, the approach taken was one of marketability. A survey of real estate brokers in the three towns was taken in an effort to determine what an acre of this shorefront land would sell for if it could be sold privately and built upon. Based on sales of comparable properties in other nearby localities and their expert knowledge of the area and demand influences a consensus was reached that the value of an acre of this land which would be lost to erosion in the 20-mile study area would fall between $60,000 and $85,000. A figure of $70,000 was used. A rough approximation of land lost (485 acres) multiplied by price per acre ($70,000) and then divided by 50 years results in an annual average loss of $679,000. Annual losses of other physical developments such as bathhouses, parking lots, roads, houses, lighthouses and radio towers over the 50-year project life amount to an additional $105,600 per year. A specification of these damages is in the summary. Total physical damages prevented by the structural alternatives thus equals $784,600 annually.

Increased Recreational Usage

The following analysis attempts to arrive at an estimation of dry beach space available for recreational purposes in the 20-mile project area. The net recreational benefit attributable to a beach erosion control project is the net increase in recreational facilities with the project over that without the project. A necessary first step is to estimate present recreational beach capacity, the present level of demand and the potential future demand for beach space. The entire project area will be examined first in its entirety, then individually by town and beach. Table 3-10 displays the estimated capacity and potential maximum use as constrained by the present state of development. Of the twelve beaches open to the public located within this 20-mile stretch, five are owned and operated by the National Park Service as parts of the Cape Cod National Seashore, three are owned by the town of Truro and four by the town of Wellfleet. Total beach area within the project limits is divided almost evenly between town beaches and CCNS beaches.

The salient point represented by the data in Table 3-10 is that there is an extreme excess supply of recreational dry beach area within the project area. Roughly 10,862,000 sq. ft. (249 acres) of dry beach exists. Employing the measure of 75 sq. ft. per person as a minimum measure of beach space Water Resources Council, "Principles and Standards for Planning; Water and Related Land Resources") an approximate aggregate of 144,800 people could use the beaches to maximum capacity. This maximum number serves only as an ideal since it could never be reached due to a variety of factors. For example, some stretches of beach are used for other activities such as dune buggies, fishing, etc. and not solely bathing. In certain cases beaches are also kept underutilized and controlled for the convenience of town residents or to keep in character with the undeveloped nature of the CCNS, in opposition to the more developed and crowded beaches on the mid-Cape and south-Cape. In general the primary reasons for the 90 percent unused beach capacity are:

1. Lack of adequate parking at existing lots
2. Walking distance from parking areas to available beach
3. Lack of access roads and parking lots at various beach locations.
4. Lack of facilities: bathhouses, snack bars, etc.
5. Extent of lifeguard services and beach patrols
6. Undertoe and riptide problems at certain bathing areas.

The data in Table 3-10 for beach use and capacity was developed from National Park Service records and where no records existed, especially for the town beaches, estimation procedures were employed. Estimations were based on the following assumptions:

1. The beach season extends from mid-June to the first week in September and consists of 60 days (75 percent of total potential days due to inclement weather).

Table 3-10. Recreational Use of Principal Public Beaches

Beach	Length in Miles	Usable Dry Beach Area in Sq. Ft.	Maximum Daily Capacity[1]	Parking Spaces	Average Estimated Auto Users[2]	Estimated Walkers and Bicyclists	Estimated Drop-Offs	Average Total Daily Users[3]	Unused Beach Capacity
Head of Meadow (NPS)	4.4 (combined)	2,033,000 (combined)	27,100 (combined)	400	1,800	50	—	1850	90%
Head of Meadow (town)				200	900	50		950	90%
Highland	1.5	396,000	5,280	100	450	50	50	550	90%
Longnook	1.5	792,000	10,560	45	20C	50	50	300	97%
Ballston	2.5	1,320,000	17,600	125	560	50	50	660	96%
Newcomb Hollow	1.2	1,077,000	14,360	275	1,240	0	0	1,240	91%
Cahoon Hollow	1.2	444,000	5,920	75	340	0	0	340	93%
White Crest	1.0	317,000	4,230	50	225	0	0	225	94%
LeCount Hollow	1.4	444,000	5,920	150	675	300	200	1,175	80%
Marconi	2.4	1,584,000	21,120	600	2,700	0	0	2,700	87%
Nauset Light	1.5	1,188,000	15,840	157	700	200	0	900	96%
Coast Guard	1.6	1,267,000	16,900	355	1,600	200	0	1,800	89%
TOTALS	20.2	10,862,000	144,830	2,532	11,400	950	350	12,700	91%

[1]assumes 75 sq. ft. per person [2]assumes 4.5 persons per car [3]assumes full parking lots

2. Total auto users (total parking spaces x 4.5 persons per car) were assumed to be at a maximum for all 60 days due to the resort character of the area.

3. Estimates of walkers, bicyclers and drop-offs were made where applicable.

4. Weekday and peak-day use (weekends and holidays) were not separated. All use was assumed to be peak day (maximum capacity of lots) due to the nature and attraction of the area.

In general, expanding population and rising personal income coupled with general trends toward more leisure time and greater mobility have increased pressure on the recreational supply-demand relationship on the lower Cape, mid-Cape and Bay side. However, in the Easterly Shores project area, the protection afforded the area by the Cape Cod National Seashore has preserved large areas of natural beach solely for public use.

Since the recreational beach supply has been established it is necessary to examine the future demand for this existing space. Due to the unique natural and unspoiled character of the project area beaches and the attraction of the Cape Cod National Seashore facilities, the beaches draw not only from the six towns but from the entire Cape. A general indicator of future demand is projected increase in the summer population of the six towns and entire Cape Cod area to 1995, which is presented in Table 3-11 below.

Table 3-11. Projected Summer Population*

	1975	1995	Increase	% Increase
Provincetown	16,900	20,000	+3,100	+18%
Truro	11,900	17,000	+5,100	+43%
Wellfleet	13,400	19,000	+5,600	+42%
Eastham	16,400	23,000	+6,600	+40%
Orleans	11,500	18,000	+6,500	+57%
Chatham	19,500	26,000	+6,500	+33%
Total Cape Cod	382,000	570,000	+188,000	+50%

*Projections by Phillip B. Herr & Associates, April 1976.
Peak population in winter residences, second homes and non-dwelling accomodations.

Except for Provincetown which is nearing the saturation point, substantial gains in summer population are expected to occur overall on Cape Cod (+50%), particularly in the five other project area towns by the year 1995. A commensurate increase in beach demand or even a doubling in the project area beaches to 1995 would result in use approaching only 20 percent of capacity. This assumes that the usual buildup of beach that occurs every spring following the stormy winter erosion period will continue to occur. While dry beach space will be available, the roads leading to and from

parking lots servicing the beaches will be severely strained. The decision concerning future access to the beaches and volume of users remains with the National Park Service (N.P.S.) and the towns. The first and primary problem is parking space based on the fact that there is little residential development in the area near the beaches precluding large numbers of walkers and drop-offs and necessititating vehicular travel.

Because the N.P.S. is the largest landowner in the project area, their position on beach erosion and parking facilities should be included. The N P.S. is particularly concerned with erosion at Coast Guard Beach, Ballston Beach and Herring Cove. They state that feasibility control measures for these three areas especially should be investigated. "However when considering implementation of such methods, it should be remembered that shore erosion on the outer Cape is part of the natural order. It may well be that such implementation would damage the natural resource more than no protection at all." Concerning parking, the N.P.S. has suggested the study of such systems as central parking facilities with public transportation to the beach. It can be inferred that the N.P.S. does not steadfastly hold to parking abutting the beaches, especially in light of recent parking lot damage at Coast Guard Beach.

A description of each beach in the project area with a demand-supply analysis follows:

TRURO:

There are five beaches in Truro open to the public which account for approximately 10 miles of shoreline. The northernmost beach is Head of the Meadow beach which is composed of the National Park Service beach and an adjoining beach operated by the town of Truro.

Both beaches combined account for a length of approximately 4.4 miles and have a width of 75 to 100 feet. Parking spaces for 200 cars are available at the town beach while 400 parking spaces are available at the N.P.S. beach. There is a bathhouse facility at the N.P.S. beach and both beaches have bicycle racks. Head of the Meadow (both beaches) are the last to fill up on weekdays and weekends according to the Truro Police Department. A possible reason is the distance from tourist lodgings. The National Park Service estimates that most beach users will not drive more than five miles from their lodgings to use a beach. Hence the concentration of persons in the Provincetown area will visit Race Point beach and Herring Cove in Provincetown instead of Head of the Meadow which is approximately twelve miles south. Estimated maximum daily use which is constrained by parking facilities amounts to roughly 3,000 persons. Available dry beach area could accommodate a maximum 33,000 persons resulting in excess capacity of 90 percent.

Highland Beach extends for roughly 1.5 miles and its width varies from 0 to 25 feet from cliff to high water in its north end to 75 to 100 feet from dunes to high water in the south. There is no specific parking lot for this beach; however, some persons park in the golf course parking lot and other locations resulting in approximately 100 parking spaces. Due to such

factors as the limited parking, steep drop down the dunes from the road to beach and presence of the Coast Guard station with its restrictions, Highland Beach does not get particularly heavy use. Maximum daily use in light of existing conditions is estimated at roughly 500 people while the existing beach could accommodate a maximum 3,000 resulting in an existing excess capacity of 85 percent.

Longnook Beach, which is bordered on the north by the Truro Air Force station and on the south by the Green Hills Radio Towers, extends for approximately 1.5 miles. Beach width varies from 75 to 150 feet from high water to dunes. A small parking lot (45 spaces) and bicycle rack are located at the end of narrow Longnook Road, the only access road to the beach. There is a very steep (50- to 75-foot) drop down the dune from the area fronting the parking lot to the beach. In spite of these features Truro police report that this beach is the most popular in Truro and is full by 10 a.m. weekdays and weekends with illegal parking, ticketing and towing occurring regularly on Longnook Road. Ideally enough, beachspaces exist to accommodate some 11,000 people but parking and other constraints limit maximum use to 300 people leaving roughly 97 percent excess capacity. Utilizing this excess capacity would involve an obvious enlargement of parking and provision of stairways to the beach area.

Ballston Beach in Truro is second in popularity to Longnook and its parking lot is usually filled by 12 noon weekdays and weekends. Ballston is an excellent bathing beach, 2.5 miles in length, 75 to 100 feet wide and having fine sand. There is parking for 125 cars and a bicycle rack is available. Access is by North and South Pamet Roads and illegal parking problems also exist at this beach. Although there is an abundance of available beach space (20,400 persons at 75 square feet per person) parking and parking restrictions constrain maximum daily use to 600 to 1,000, leaving 95 percent unused capacity.

It is evident that excess capacity for recreational beach space exists in Truro. This coupled with the sparsity of shorefront development will not result in sufficient economic benefits to justify the cost of structural alternatives.

WELLFLEET:

The town of Wellfleet has four town beaches and one National Park Service beach totalling roughly 7.2 miles of shoreline.

Newcomb Hollow Beach is owned by the town and extends southerly from the Truro-Wellfleet town line for approximately 1.2 miles to Cahoon Hollow Beach. Newcomb Hollow is also an excellent beach having a width of from 125 to 175 feet and is well suited to bathing and dune buggy activities. A parking lot at the beach has 275 spaces with access from the west (Rt. 6), by Gull Pond Road and from the south by Ocean View Drive. Maximum possible bather capacity of used beach area is approximately 14,000 with present maximum daily use constrained by parking to 1,300 leaving roughly 90 percent unused capacity in the sense of bathing, not dune buggies.

Cahoon Hollow Beach is the natural extension of Newcomb Hollow Beach for another 1.2 miles southward. The beach becomes narrow to a width of 70 feet and the sand turns from fine in the north (Newcomb Hollow) to coarse in the south. Access is gained from Ocean View drive north and south and by Long Pond Road from the west (Rt. 6). The beach is used primarily for bathing and dune buggy activities and there is a considerable drop (50 feet) down the dunes from the parking lot to the beach. Parking is minimal, only 75 spaces, severely constraining beach use to roughly 400 persons while available maximum capacity is 5,400, leaving roughly 90 percent unused capacity.

White Crest Surfing Beach runs southerly from Cahoon Hollow for about one mile and is used primarily for surfing activities. Access is from Ocean View Drive on the north and south and the 50-space parking lot is directly off the drive. The beach is narrow and the sand not of good quality with some rocks present on the shore. The location and size of the parking lot and condition of the beach make White Crest not well suited for swimming but make it a good location for surfing activities. Excess capacity is roughly 90 percent as in most other beachs.

LeCount Hollow Beach is located off the southern terminus of Ocean View Drive and the eastern end of LeCount Hollow Road. It is the only beach in the project area that has a concentration of residences near the beach allowing walking and bicycling and not sole dependence on vehicle conveyance to the beach. At least twelve streets with many houses on each street are within walking distance of the beach. The beach extends for 1.4 miles and varies in width from 55 to 70 feet. Parking is available for 150 cars and access is available from Rt. 6 (west) and Ocean View Drive (north). Maximum daily capacity of the beach (allowing 75 square feet per person) is approximately 5,900. Estimated auto users, walkers, drop offs and bicyclists bring use to approximately 1200 to 1500 daily which results in roughly 75 percent excess capacity.

Marconi Beach is a National Park Service beach which extends 2.5 miles from Marconi Station to the Wellfleet-Eastham town line. The beach varies in width from 100 to 150 feet from the dunes to high water and is composed of fine beach sand. Parking for 600 cars and full bathhouse facilities are available. Average maximum total daily use is estimated at 2700 to 3000 and is constrained by parking. N.P.S. records indicated use at only slightly below this estimated figure. However, due to the length and width of the beach there is excess capacity of between 85 to 90 percent. As is the case with Truro, the shoreline in Wellfleet contains excess recreational space and a lack of shorefront development which results in insufficient economic benefits to economically justify the cost of the structural projects.

EASTHAM;

The 20-mile study area ends in Eastham with the inclusion of two additional N.P.S. beaches -- Nauset Light and Coast Guard. Nauset Light Beach, located at the end of Cable Road, has a parking lot for 150 cars on a bluff 50 feet

As is the case with Truro, the shoreline in Wellfleet contains excess recreational space and a lack of shorefront development which results in insufficient economic benefits to economically justify the cost of the structural projects.

EASTHAM;

The 20-mile study area ends in Eastham with the inclusion of two additional N.P.S. beaches -- Nauset Light and Coast Guard. Nauset Light Beach, located at the end of Cable Road, has a parking lot for 150 cars on a bluff 50 feet above the beach. The dune erosion has reached the front of the parking lot and a stairway is available at the south end of the parking lot which leads down to the beach. This beach is a National Park Service beach, approximately 1.5 miles in length, 100 to 200 feet in width and is used for swimming and surfing. Due to the fact that surfers use this beach heavily because of big breakers (quite common) and its accessibility, the parking lot is usually full by 9 a.m. on many summer days. While the total capacity of Nauset Light Beach is roughly 11,000, Park Service records indicate an average daily use of 1,500 over the period 1954-76. While excess capacity is roughly 85 percent at the beach, the obvious cause is the small parking area.

The southernmost beach in the 20-mile study area is Coast Guard Beach, a National Park Service beach located one mile south (down Ocean View Drive) from Nauset Light Beach. Access is gained easily from the west down Nauset Road. This beach is the most visited of all those in the Cape Cod National Seashore; total annual visits have averaged over 151,000 per year for the years 1974-76. Some reasons for the heavy volume of visitor traffic are that Coast Guard is the first beach that one encounters upon entering the National Seashore from the south and the Salt Pond Visitor Center is located on Route 6 at the head of the road which leads to the beach. Between the Visitor Center and the beach there are bicycle trails and a picnic area. A full bathhouse facility and parking for 355 cars existed prior to the February 1978 storm; however, the bathhouse was entirely destroyed and the parking lot sustained severe damage. Past experience shows that the parking lot fills to capacity on each sunny sumer weekday and cars are turned away on weekends. The beach is approximately 1.5 miles long and is approximately 125 to 150 feet in width with the N.P.S. patrols extending about 1000 feet. Optimum capacity would be roughly 15,500 people, but again the parking facilities constrain maximum use to 1,800 to 2,000, leaving excess capacity of 85 to 90 percent.

The aforementioned twelve beaches in the towns of Truro, Wellfleet and Eastham are those included int he 20-mile limits for structural alternatives (Plans I through VII). Plan VIII is a plan for dune restoration, planting of dune grass, fertilizing etc. The plan would extend approximately 23 miles south from the southern end of Coast Guard Beach. One more beach would be included in the analysis, Nauset Beach in Orleans, which is owned and oprated by the town of Orleans. Similar measures could be employed at Herring Cove and Race Point beaches in Provincetown (see Table 3-12).

Table 3-12. Beaches Included in Plan VIII

Beach	Length in Miles	Usable Dry Beach Area in Sq. Ft.	Maximum Daily Capacity[1]	Parking Spaces	Average Estimated Auto Users[2]	Estimated Walkers & Bicyclers	Estimated Drop-Offs	Average Total Daily Users[3]	Unused Beach Capacity
Herring Cove	1 mile	435,600	5,800	750	3375	75	50	3500	40%
Race Point	3.3 incl. jeep trail	2,613,600	34,800	300	1350	150	--	1500	95%*
Nauset Beach (Orleans)	.5	343,200	4,600	700	3150	300	200	3650	20%

1 assumes 75 sq. ft. per persons

2 assumes 4.5 persons per car

3 assumes full parking lots

* due to long jeep trail and dune buggy use

above the beach. The dune erosion has reached the front of the parking lot and a stairway is available at the south end of the parking lot which leads down to the beach. This beach is a National Park Service beach, approximately 1.5 miles in length, 100 to 200 feet in width and is used for swimming and surfing. Due to the fact that surfers use this beach heavily because of big breakers (quite common) and its accessibility, the parking lot is usually full by 9 a.m. on many summer days. While the total capacity of Nauset Light Beach is roughly 11,000, Park Service records indicate an average daily use of 1,500 over the period 1974-76. While excess capacity is roughly 85 percent at the beach, the obvious cause is the small parking area.

The southernmost beach in the 20-mile study area is Coast Guard Beach, a National Park Service beach located one mile south (down Ocean View Drive) from Nauset Light Beach. Access is gained easily from the west down Nauset Road. This beach is the most visited of all those in the Cape Cod National Seashore; total annual visits have averaged over 151,000 per year for the years 1974-76. Some reasons for the heavy volume of visitor traffic are that Coast Guard is the first beach that one encounters upon entering the National Seashore from the south and the Salt Pond Visitor Center is located on Route 6 at the head of the road which leads to the beach. Between the Visitor Center and the beach there are bicycle trails and a picnic area. A full bathhouse facility and parking for 355 cars existed prior to the February 1978 storm; however, the bathhouse was entirely destroyed and the parking lot sustained severe damage. Past experience shows that the parking lot fills to capacity on each sunny summer weekday and cars are turned away on weekends. The beach is approximately 1.5 miles long and is approximately 125 to 150 feet in width with the N.P.S. patrols extending about 1000 feet. Optimum capacity would be roughly 15,500 people, but again the parking facilities constrain maximum use to 1,800 to 2,000, leaving excess capacity of 85 to 90 percent.

The aforementioned twelve beaches in the towns of Truro, Wellfleet and Eastham are those included in the 20-mile limits for structural alternatives (Plans I through VII). Plan VIII is a plan for dune restoration, planting of dune grass, fertilizing etc. The plan would extend approximately 23 miles south from the southern end of Coast Guard Beach. One more beach would be included in the analysis, Nauset Beach in Orleans, which is owned and operated by the town of Orleans. Similar measures could be employed at Herring Cove and Race Point beaches in Provincetown (see Table 3-12).

Herring Cove Beach is located along the western shore of Provincetown, approximately 2 miles from the center of Provincetown. This beach is second in popularity to Coast Guard Beach, due mainly to its location at the terminus of Rt. 6 and its being adjacent to the densely populated residential area of Provincetown. The beach is fully developed with a large bathhouse, parking for 750 cars, an asphalt seawall and stone groins for beach protection. Lifeguards patrol 1500 feet of the beach, which is 1 mile in length and approximately 75 to 100 feet in width. Optimal capacity is about 6,200 people. With existing conditions and facilities, a maximum of 3500 people could use the beach at any one time, leaving roughly 45 percent excess space.

This beach is an area of both erosion and accretion but erosion has predominated in recent years.

Race Point Beach is located on the northern coast of Provincetown east of the lighthouse. Access is gained by Race Point Road from Rt. 6 and the Provincetown Airport is just inland from the beach. The beach which stretches for 3.3 miles and varies in width from 100 to 200 feet, is used for dune buggy activities in addition to bathing. There is a bathhouse at the beach and parking spaces for 300 cars. Race Point Beach is 3.3 miles long with about one mile used for bathing and the remainder for dune buggy activities. If adequate parking and access were available to the entire stretch of beach, excess capacity would be 95 percent; using the one-mile beach a figure of 90 percent is applicable. Park Service records indicate average daily use of 1,100 for the years 1974-76 which comes quite close to estimated capacity constrained by present facilities.

Nauset Beach in Orleans, the most developed and most heavily used of all town-owned and operated beaches in the study area, is located just south of Nauset Harbor and Nauset Heights and access is gained eastward on Main Street and Beach Road from Routes 6, 6A and 28. Many motels are within walking distance of the beach, which is used heavily not only by tourists but by Orleans taxpayers who are given parking stickers. This beach has faull facilities: bathhouse, snack bar, lifeguard patrol, 700 parking spaces and a bicycle rack for 125 bicycles. Local officials estimate that the parking lot is filled in the morning every weekend day and peak day resulting in roughly 5000 people on the beach. On weekdays beach users number approximately 3000. The dimensions of Nauset beach (one-half mile in length and 130 feet in width), coupled with the large parking lot and convenient location, have resulted in beach use currently reaching capacity. However, additional beach space is available and could be developed at the south end.

The beach at Nauset Heights extends northward for about three-quarters of a mile from Nauset Town Beach in Orleans and forms a spit extending into Nauset Harbor. The beach is unprotected but is open to the public for recreation. No facilities are available, especially parking; however, a considerable number of private homes are located within walking distance of this beach.

The southern extremity of the 46-mile project area is the Orleans/Chatham spit which extends southerly from Orleans Town Beach to the tip of the spit east of Monomoy Island in Nantucket Sound. Access is allowed only by beach buggy from the entrance at Orleans Town Beach. The vehicles must be inspected prior to entering the spit and must pay a fee. The beach area is used primarily by beach vehicles, fishermen and campers. Approximately 350 vehicles are on the spit on the weekend and 50 during the week. In addition there are 13 permanent camps on the Orleans portion of the spit and 20 in Chatham. It is present policy that these camps can be bequeathed once and then they revert to the town analogous to the policy in effect in the Cape Cod National Seashore.

Summary and Benefit to Cost Ratio

From the preceding discussion it is evident that excess recreational beach space exists in the project area; therefore benefits cannot accrue to any plan on the basis of increased recreational beach space provided. In fact, plans I, II and IV might result in the loss of beach as it is known today, and negative benefits would accrue to these plans. Benefits to each plan can be credited only under the category of "physical damages prevented." The dollar value of physical losses prevented on an average annual basis over the 50-year life of the project are:

Category		Annual Benefit
1. Loss of Land		$679,000
2. Loss of Parking Lots & Roads		17,600
3. Residences		72,000
4. Bathhouses		6,000
5. Other (lighthouses, radio towers)		10,000
	Total	$784,600

Benefit-cost ratios for the alternative plans show that no structural plan is economically justified.

		Total Annual Charges	B/C Ratio
Plan I.	Rock Revetment	2,966,000	0.26
Plan II.	Nearshore Stone Mound	12,082,000	0.06
Plan III.	Offshore Breakwater	36,428,000	0.02
Plan IV.	Concrete Section/ Slab/Mound	5,360,000	0.15
Plan V.	Stone Groins	2,170,000	0.36
Plan VI.	Stone Groins and Sandfill	6,708,000	0.12
Plan VII.	Sandfill	4,792,000	0.16
Plan VIII.	Dune Restoration	981,000	

EFFECTS ASSESSMENT

The Without Project Condition

The without project condition is characterized by continued erosion. It has been estimated that the bluffs along the 20-mile structural alternatives project area have been eroding at an average rate of three to five feet per year with greater losses occurring during severe storms and at times of exceptionally high tides. Using this figure as an average for yearly loss, it can be aniticpated that approximately 485 acres of shoreland consisting of dunes and bluffs would be lost over a 50-year period. Erosion does not occur at a constant rate for the project area and most likely will be more severe in some locations.

Because there is no commercial or industrial development and residential development is light along the project area coastline, damages without a project over the 50-year period of analysis would be limited to lands, several houses, roads, parking lots, lighthouses and other existing beach facilities and structures.

Some of the more popular beach areas within the boundaries of the National Seashore that will be affected by erosion over the next 50 years are in Truro. The areas likely to suffer most from erosive forces lie along Ballston Beach, Longnook Beach and Highland Beach. There are approximately 250 parking spaces, as well as twenty to thirty houses that would be subject to damages from erosion. Some Coast Guard facilities, including a radio tower and lighthouse in the area of Highland Beach would also be lost.

In Wellfleet four town beaches and one National Park Service beach will be subject to damage. Newcomb Hollow and Marconi Beaches are the more popular and have parking lots accommodating over 800 vehicles. These parking areas and access roads, as well as a bathhouse at Marconi, would be lost to erosion. Continued erosion along LeCount Hollow Beach would threaten several homes near the beach.

Two National Park Service beaches front the coastline in Eastham, Nauset Light and Coast Guard. These beaches receive considerable use because they are the first encountered upon entering the National Seashore. Erosion along these two beaches is likely to destroy parts of roads and parking lots and sash out areas along the tops of banks where houses are located especially along Nauset Light Beach. A full bathhouse facility and a portion of the parking lot at Coast Guard Beach were severely damaged during the February 1978 storm.

The coastal areas will experience limited development because they are protected by regulations established by the Cape Cod National Seashore. Any development within the Seashore will be for recreational uses including new trails for hiking, biking and horseback riding, new access roads to certain recreational areas, improved parking facilities, bathhouses and comfort stations. Because the Seashore has adopted a "do nothing" policy in regard to erosion, new facilities will be carefully planned to reduce problems created by the natural erosive forces.

APPENDIX 4

CONTRIBUTION AND COORDINATION WITH OTHER INDIVIDUALS, ORGANIZATIONS, AND AGENCIES

PREPARED BY THE NEW ENGLAND DIVISION

CORPS OF ENGINEERS

DEPARTMENT OF THE ARMY

CONTRIBUTION AND COORDINATION WITH OTHER INDIVIDUALS, ORGANIZATIONS, AND AGENCIES

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SECTION A

UNITED STATES CORPS OF ENGINEERS

SECTION A

UNITED STATES CORPS OF ENGINEERS

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INTRODUCTION

The Congress of the United States has given the Corps of Engineers the authority to undertake beach erosion control studies at no cost to State and municipal government agencies, along publicly owned or publicly used shorefront areas. Congress, recognizing the need to restore and protect the Nation's shoreline, initiated legislation permitting the Corps of Engineers to join local forces in the fight against beach erosion. Shore protection may be structural or nonstructural in nature. The Corps has been developing methods of shore protection since 1930. Division and District Engineers of the Corps have their professional staff available to advise and assist State and local government with shore erosion problems at all times. Beach and shore erosion is a national problem, and the increasing Federal interest has been paralleled by the expanding interest of the coastal States.

As this Federal interest in shore protection and beach restoration has increased, so has the involvement of the Corps. By various legislative actions, Congress has directed the Corps to research, investigate and study the causes of beach erosion and, in certain cases, to construct shore protection and beach restoration projects. This program is conducted by the Coastal Engineering Research Center at Fort Belvoir, Virginia. Universities and private research organizations are also under contract to the Center. Other significant programs are carried out by the U.S. Army Engineers Waterways Experiment Station (WES), Vicksburg, Mississippi.

SECTION B

UNITED STATES SOIL CONSERVATION SERVICE AND EXTENSION SEA GRANT ADVISORY PROGRAM

SECTION B

UNITED STATES SOIL CONSERVATION SERVICE AND EXTENSION SEA GRANT ADVISORY PROGRAM

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INTRODUCTION

The Cape Cod region is a dynamic landscape of natural glacial processes influenced by winds, tides, storms and man's activities. In its efforts to develop plans to preserve this valuable coastal area, the New England Division was assisted by the United States Department of Agriculture, Soil Conservation Service; the Cooperative Extension Service, University of Massachusetts; and the Massachusetts Institute of Technology Sea Grant Program. Included in this appendix is a series of brief reports, including letters, publications and other useful information on various types of plants and fertilization for use along the outer Cape coast.

REPORTS

The following is a series of brief letter reports submitted in response to a request for assistance concerning available plants, fertilizer and methods used in retarding erosion in this dynamic area.

UNITED STATES DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

29 Cottage Street, P.O. Box 848, Amherst, Massachusetts 01002

June 1, 1978

Mr. Thomas Bruha
Department of the Army
New England Division
Corps of Engineers
424 Trapelo Road
Waltham, Massachusetts 02154

Dear Tom:

Attached is the paper I prepared for your use in your erosion control study. Please call me if you need more information, or if you want to suggest changes in this material.

Sincerely,

Philip Christensen
Assistant State Conservationist
for Water Resources

Attachment

cc
Dr. Benjamin Isgur, with attachment

SOIL CONSERVATION SERVICE ASSISTANCE WITH THE
MANAGEMENT OF COASTAL EROSION AREAS IN MASSACHUSETTS

Introduction

The Massachusetts coastline varies from sandy beaches--to vertical cliffs--to rockbound shorelines. Much of the more than 1,000 miles of shoreline is eroding. In these areas, the dynamic forces of nature are greater than the resisting capabilities of the soil, rock or man-made structures. Residents, local governmental officials and others are concerned about these eroding areas and often seek help to control the erosion. Many coastal erosion programs have been devised and hundreds of thousands of dollars have been spent to control local erosion problems. It is time we changed our emphasis from coastal erosion control to management of coastal erosion areas.

Coastal Erosion Areas

Eroding areas along the coastline can be placed in three general categories. These categories and a recommended management policy for each are as follows:

1. Areas where there is minor soil erosion caused by excessive runoff wave action or lack of adequate vegetation and where normal vegetation and management practices or minor structural measures can stabilize the areas: Landowners and communities can solve most of these problems using currently available technology and assistance from local, state and federal agencies.

2. Areas where significant erosion caused by wave action or a combination of wave action and surface runoff, is damaging high value property or development, and where feasible alternatives can be implemented to stabilize these areas: These problem areas must be identified and a system of priorities established for solving the problems. State, federal and local technical and financial assistance must be coordinated to help solve the highest priority problems. Solutions may include major structural measures, reshaping, relocation of facilities, vegetation, and other currently available technical measures. Studies to be used in setting priorities and identifying feasible solutions must include environmental assessments and economic feasibility determinations.

3. <u>Areas where significant erosion caused by wave action, or a combination of wave action and surface runoff, damages land masses where high value property or development does not exist, or where feasible solutions have not been identified</u>: These areas should be identified as critically eroding areas and as a fragile component of the coastal zone. Land use plans for adjacent areas must recognize the intense dynamic nature of this part of the shoreline and restrict development that will be subject to damage as the erosion progresses. Large scale efforts to stop the erosion should not be made. Minor efforts to slow the rate of erosion by diverting surface water away from the area or by establishing temporary vegetation could be made by the landowner if desired.

The application of these principles permits us to recognize the different types of erosion, acknowledge the dynamic nature of the coastline and admit that there are areas where erosion need not be "controlled" but land use policies should be developed which preclude future development in these areas.

<u>Soil Conservation Service Assistance</u>

The Soil Conservation Service (SCS) can help state and local agencies develop an appropriate management program by contributing to the identification and categorization of these types of problems and can provide assistance in controlling shoreline erosion in categories 1 and 2, if the following conditions can be met:

1. The problem is not created by wave action on the open and unprotected shore of the ocean.

2. The problem can be solved with vegetation, upland erosion control practices, or minor structural measures where the structural measures are not higher than three feet above mean high tide.

3. Failure of structural measures will not cause an immediate hazard to life or result in serious damage to buildings, residences, roads, or other high valued property.

4. Installation of the measures will have no significant adverse effect on the environment or on adjacent lands, waters, or installations.

5. Sponsors and cooperators understand the level of protection being provided and their responsibility for maintenance and repair.

6. Plans and schedules for installing structures and establishing vegetation are acceptable to local, state and federal agencies that have jurisdiction in the areas concerned.

Although assistance can not be provided by the SCS to solve erosion problems created by wave action on the open and unprotected shore of the ocean, SCS can provide assistance on complementary erosion control practices to be used in conjunction with complex or expensive installations built by others at these locations. Technical assistance on the minor shore erosion problems of individual landowners in category 1, can be provided through the conservation districts, subject to the assignment of priority by the districts.

The SCS can provide technical and financial assistance for eligible critical area treatment measures in The Pilgrim Resource Conservation and Development (RC&D) Area (Barnstable, Bristol, Dukes, Plymouth, and Nantucket Counties). Funds may be provided for up to 75 percent of the cost of construction of measures on critically eroding areas which cannot be stabilized by ordinary conservation treatment and management, and which, if left untreated, would cause severe sediment and erosion damages adversely affecting the community or the general public. Priorities for this assistance are established by The Pilgrim Area RC&D Council and all construction activity is based on a detailed measure plan prepared by the local sponsors and the Soil Conservation Service.

The SCS assists communities in the development and evaluation of land and water use policies and plans through the Massachusetts Natural Resources Planning Program (MNRPP). This program, which receives technical agency assistance and support, utilizes local citizens in identifying the town's resource base and in establishing land use plans and policies. Through this program towns could evaluate coastal erosion areas and establish appropriate management policies.

Vegetation of Coastal Erosion Areas

Several ecological systems are present within the coastal area of Massachusetts. These include salt marsh, tidal flats, eelgrass flats, sand beaches, rocky shores, and sand dunes. Composite systems include salt ponds, estuaries, barrier beaches and islands. This page will focus on erosion control on sand dunes, barrier beach, and islands systems.

The sand dune system is divided into several zones, extending from the sea to the interior of Cape Cod. These zones include: beach face, fore dune, interdune, high dune, maritime forest, back dune, swamp, and mature maritime forest (Ecosystems and Resources of the Massachusetts Coast, CZM, 1975). Barrier beaches and islands may contain two or more of these zones. The interior of Cape Cod is considered as representing the mature maritime forest zone.

The beach face is unstable and undergoing dynamic change. Vegetation usually includes beachgrass and beach pea where stable areas are encountered. The fore dune is characterized by beachgrass, beach pea, dusty miller, seaside goldenrod, and is highly exposed to salt spray. The interdune may include the aforementioned plants plus beach heather, and affords some protection from salt spray. The high dune is exposed to salt spray, wind, and plants are subject to drying out. Beachgrass is usually found on this dune area. The maritime forest is protected by the high dune and features staghorn and smooth sumac, beach plum, honeysuckle, bayberry, and rugosa rose. Back dunes include stands of pitch pine. Swamps or low interdune areas provide protection for red maple, black tupelo gum, alder, arrowwood, shadbush, willow, highbush blueberry, and white cedar. Mature maritime forests are well protected from salt spray and include black oak, black cherry, pitch pine, quaking aspen, red cedar, sassafras, gray birch, Japanese black pine, and American beech.

Weather vagaries and man's activities often damage struggling vegetative systems in these fragile areas. Sand "blow-outs", fire, and "walking dunes" often result from mining, road construction, residential development, utility line installation, and a host of other activities.

Fertilization and traffic control on existing vegetation are essential components of effective erosion management systems. Soil testing to determine plant nutrient needs is recommended.

Mulching aids in the reduction of surface soil temperature, moisture retention, erosion control, weed control, and addition of organic matter. Wood chips, salt marsh hay and seaweed are native mulching materials that are available. Snow fencing or other structures may be needed at specific sites to protect plantings or keep mulch in place.

Tree and shrub planting stock is available from a variety of sources. Attached is a table of "Plants Adapted to Massachusetts' Coastal Areas" which may serve as a guide in plant selection.

The establishment and maintenance of appropriate vegetation for coastal erosion areas can reduce erosion and improve visual quality. Vegetation in areas subject to wave action may be temporary and can not be depended on for permanent erosion control in these areas. It is recommended that a plan be prepared for the establishment and maintenance of vegetation on any large area.

Attachment

By: Philip H. Christensen, Assistant State Conservationist for Water Resources, Soil Conservation Service, Amherst, Massachusetts, June 1978.

PLANTS ADAPTED TO MASSACHUSETTS' COASTAL AREAS

PLANTS	HT.	SPACING	ECOLOGICAL SYSTEM OR ZONE[1/]
TREES:			
Juniperus virginiana (Eastern red cedar)	30-100'	8'	BD, MMF
Pinus nigra (Austrian pine)	80'	10'	MF, BD, MMF
Pinus resinosa (Red pine)	75'	10'	MF, BD, MMF
Pinus strobus (Eastern white pine)	100-150'	10'	MMF - prefers moisture
Pinus sylvestris (Scotch pine)	75'	10'	MF, BD, MMF
Robinia pseudoacacia (Black locust)	70- 80'	7'	MF, BD, MMF
Pinus (Japanese black pine)		10'	FD, HD, ID, MF, BD, MMF

All are evergreens, except black locust.

PLANTS	HT.	SPACING	ECOLOGICAL SYSTEM OR ZONE
SHRUBS:			
Amelanchier canadensis (Shadbush)	25'	10'	S, BD, MF
Amorpha fruticosa (Indigo bush)	10'	6'	S, BD, MF
Arctostaphylos uva-ursi (Bearberry)	½'	4'	BD, MMF
Caragana arborescens (Pea-shrub)	1½'	12'	BD, MF, MMF
Clethra alnifolia (Sweet pepper-bush)	9'	10'	MF, BD, S, MMF
Comptonia peregrina (Sweet fern)	4'	8'	BD, MMF
Cornus stolonifera (Red-twig dogwood)	7'	5'	MF, BD, S, MMF
Cotoneastern horizontalis (Rock cotoneaster)	3'	8'	BD, MMF
Diervilla lonicera (Dwarf bush honeysuckle)	3'	6'	MF, BD, MMF
Elaeagnus umbellata (Autumn olive)	15'	10'	MF, BD, MMF
Genista tinctoria (Dyer's greenweed)	3'	4'	MF, BD, MMF
Forsythia Arnold dwarf (Arnold's dwarf forsythia)	3'	5'	BD, MMF
Myrica pensylvanica (Bayberry)	8'	4'	BD, MF, MMF
Rhamnus frangula (Glossy buckthorn)	15'	10'	BD, MF
Rhus aromatica (Fragrant sumac)	6'	8'	MF, BD, MMF
Rosa rugosa (Rugosa rose)	6'	8'	FD, ID, HD, MF, BD

PLANTS	HT.	SPACING	ECOLOGICAL SYSTEM OR ZONE 1/
SHRUBS: (cont)			
Rhus copallina (Shining sumac)	6'	8'	MF, BD, MMF
Rhus glabra (Smooth sumac)	20'	8'	MF, BD, MMF
Rhus typhina (Staghorn sumac)	30'	8'	MF, BD, MMF
Robinia fertilis Arnot (Arnot bristly locust)	10'	8'	MF, BD
Spiraea x vanhouttei (Vanhoutte spirea)	6'	10'	MF, BD, MMF
Vaccinium angustifolium (Lowbush blueberry)	2'	2'	MF, BD, MMF
Viburnum dentatum (Arrowwood)	15'	6'	MF, BD
Viburnum opulus (European cranberry-bush)	12'	6'	MF, BD, MMF

Of the above shrubs, all are deciduous except the semi-evergreen bayberry and rock cotoneaster. Considered as ground cover are Arnold's dwarf forsythia, bearberry, rock, cotoneaster, and lowbush blueberry. Root cuttings may be used in lieu of planting stock for Arnot bristly locust, shining sumac, sweet fern; seed may be used for Dyer's greenweed, rugosa rose, Arnot bristly locust, autumn olive, bayberry, glossy buckthorn, European cranberry-bush, bearberry, and indigo bush.

HERBACEOUS LEGUMES:			
Coronilla varia (Crownvetch)		4'	MMF (plugs)
Lathyrus sylvestris (Flat pea)			MF, BD, MMF, BF, FD, HD
Lespedeza capitata (Roundhead lespedeza)			MMF
Lespedeza cuneata (Sericea lespedeza)			MMF (Interstate variety)

All the above are perennials.

GRASSES:			
Ammophila breviligulata (American beachgrass)			All sand dune zones except swamp; Cape variety recommended.
Eragrostis curvula (Weeping lovegrass)			BD, MF, MMF
Festuca arundinacea (Tall fescue)			ID, MF, BD, MMF
Festuca capillata (Hairy fescue)			MF, BD, MMF
Panicum clandestinum (Deertongue)			MF, BD, MMF
Lespedeza japonica intermedia (VA-70 lespedeza)			MMF
Phalaris arundinacea (Kent's reed canarygrass)			S, MMF - streambank stabilization

1/ BF-beach face, FD-fore dune, ID-interdune, HD-high dune, MF-maritime forest, BD-back dune, S-swamp or low interdune, MMF-mature maritime forest.

Extension Sea Grant Advisory Program
jointly sponsored by:
Cooperative Extension Service
University of Massachusetts and
Massachusetts Institute of Technology Sea Grant Program

October 23, 1978

Reply to:

Arnold C. Lane
Cape Cod Extension Service
Deeds and Probate Building
Railroad Ave.
Barnstable, MA 02630

Mr. Thomas Bruha
U. S. Army Corps of Engineers
Trapelo Road
Waltham, Massachusetts 02154

Dear Tom,

Enclosed are some fact sheets with part of the information you desire.

Two plants that should be added to this list of vegetation for use on the bluffs or banks behind the beach are Japanese Bamboo (Polygonum cuspidatum) and Phragmites australis. (Giant Reed Grass)

Phragmites does best where there is a high water table or where an under deposit of clay creates a wet area. These wet areas are sometimes found part way up the banks or bluffs as well as near the bottom.

Poison Ivy is a very good ground cover and stabilizer but one has to be careful where he suggests its use.

To get back to the Japanese Bamboo, this plant spreads by rhizomes as does Phragmites. Both of these plants are almost impossible to kill and usually completely take over an area. The bamboo will grow to 6 feet in height and Phragmites eight to ten feet.

Plants that make their own nitrogen and are useful on banks and bluffs are Bristley Locust (Robinia fertilis) and Beach Pea.

Rick DeVergillio is putting this information in the suggestions he is sending to you.

I'll try to get the inter tidal plant list to you by next week.

We have a good supply of these fact sheets if you should like more.

Sincerely yours,

Arnold C. Lane
Regional Extension Sea Grant Specialist

ACL/cs

ESTABLISHING VEGETATION IN INTERTIDAL AREAS

Erosion in the intertidal area of bays and estuaries can be reduced and marshes built by the use of Spartina alterniflora. Marsh land creation for shore protection is a new but proven method of reducing shoreline erosion

Much of this research with man made marsh was done by Dr. W. W. Woodhouse, Jr., Dr. E. D. Seneca and Dr. S. W. Broome of North Carolina State University with support from the Coastal Engineering Research Center, U. S. Army Corps of Engineers and NOAA office of Sea Grant.

S. alterniflora is the dominant specie of the regularly flooded intertidal zone and is considered to be the most productive marsh type. Techniques have been developed for propagating S. Alterniflora by seeding and transplanting. Transplants are more vigorous and better able to survive on exposed sites and at lower elevations.

Selecting a site within the proper elevation zone for growth of S. alterniflora is critical. The upper and lower limits of growth can be predicted by checking nearby established stands. A good rule of thumb for the vertical range of S. alterniflora is from mean sea level to mean high water. Transplants should be dug from natural marshes in the same vicinity as the planting area.

Hand planting of transplants is more economical on small irregular areas. Single stem plants should be set to a depth of 10 to 15 centimeters and the soil firmed around them. Common spacing between plants is about .9 meters with plants staggered in rows. More exposed sites will benefit from closer spacing.

April and May are the best months for transplanting but successful planting can be done most of the year. Plants can be dug from a natural stand with shovels or mechanically with a small back-hoe. The up-rooted material should be separated into good sized single stem plants. Plants should be stacked, roots down, in tubs or boxes for transportation to planting sites. Material that cannot be planted within a day or two should be healed in in trenches within the intertidal zone.

(more)

Development of transplanted or seeded areas is rapid. After two growing seasons there is little difference in appearence and primary productivity of the vegetation between artificially propagated marshes and long established natural marshes.

The standing crop of above ground growth of S. alterniflora growing on a sandy substrate will be increased significantly by the addition of nitrogen alone and increased more when phosphorus is also applied. In marsh developed on finer textured sediments, nitrogen fertilizer should increase the standing crop, but there will be little response to phosphorus.

It is feasible to try to establish vegetation on many intertidal areas if it can be adequately protected from storm damage for the first growing season.

1. Propagation of Spartina alterniflora for Substrate Stabilization and Salt Marsh Development
Prepared by: W. W. Woodhouse, Jr., E. D. Seneca and S. W. Broome
Technical memorandum #46 August 1974

ACL/es
10/27/78

Prepared by:

Arnold C. Lane, Regional Extension Sea Grant Specialist

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
477 Main Street, Yarmouth Port, Ma. 02675 Telephone: 362-9332

October 30, 1978

Mr. Thomas Bruha
Department of The Army
New England Division
Corps of Engineers
424 Tropelo Road
Waltham, Mass. 02154

Dear Tom,

Attached is the report entitled 'Vegetative Soil Stabilization Techniques for Coastal Erosion Areas' for your use in your erosion control study. The report addresses dune systems and eroding bluffs. A report dealing with inter-tidal vegetation establishment will be forwarded to you directly from Red Lane, Cape Cod Extension Service.

Please call if you have any questions.

Sincerely,

Rick DeVergilio

Rick DeVergilio
Soil Conservationist

Vegetative Soil Stabilization Techniques For Coastal Erosion Areas

This report focuses on the establishment of soil stabilizing vegetation within barrier dune systems and eroding bluffs.

The information contained in this report has been generated through studies and observations made during the past 15 years by the Massachusetts Cooperative Extension Service's Sea Grant Advisory Program, and the USDA Soil Conservation Service's Plant Materials Program.

Situation: Barrier Dune System

Site Conditions: Droughty, infertile sand, exposure to varying degrees of drying wind, salt water spray and shifting sand.

Treatment Techniques:

Encourage Growth of Existing Vegetation

- fertilize growth with 10-10-10 analysis fertilizer (preferably in Spring) at rate of 800 lbs./acre (20 lbs./1000 sq. ft.)
- Control traffic within these areas.

Establish 'American Beachgrass' Within Bare Sand Areas Subject To Drifting Sand

- Transplant from nearby stands or purchase from nurseries (see sources of supply).
- Plant within period from January through March when sand is not frozen.
- Use 2-3 culms (stems) per hole.
- Set culms 6-8" deep and 18" apart in a row.
- Space rows 18" apart and stagger plants with those of adjoining row. (this spacing requires about 19,000 plants per acre)
- Space plants 12 inches apart where severe winds are expected and greater protection is required.
- If a gentle slope on the face of the dune is desired, plant the first few rows of the outer edge on a 24x24 inch spacing.
- Fertilize plantings with 800 lbs. of 10-10-10 analysis fertilizer in Spring, preferably in month of April.
- Maintain plantings by fertilizing for each of the first 2 years followed by an application once every two years thereafter.
- Provide protection from winds for new plantings by utilizing snow fencing and/or brush (discarded Christmas trees).
- Provide protection from physical trampling of plants from foot or vehicular traffic.

Establish Weeping Love Grass Within Bare Sandy Areas Not Subject To Drifting Sand

- Seed at rate of 5 pounds per acre between the period of May 1st to June 15th (the seed does not germinate until the soil is warm, yet requires rainfall to provide sufficient growth to over winter)
- Apply seed with cyclone seeder and rake or harrow into the sand.
- Fertilize at time of planting with 800 lbs./acre (20 lbs./1000 sq. ft.) 10-10-10 fertilizer.
- Avoid cutting lovegrass stands. If necessary, do so, only after the grass has produced a seed crop for next year's growth.

Establish Native Herbaceous and Woody Plant Material Within Well Established Beachgrass Stands

- choose species according to its adaptability to a specific dune zone. (The following lists specific dune zones, as described in the report "Ecosystems and Resources of the Massachusetts Coast," CZM, 1975 and lists plant materials adapted to each.

Beach Face (Unstable and undergoing dynamic change)
beachgrass and beach pea

Fore Dune (highly exposed to salt spray)
beach grass, beach pea, dusty miller, seaside goldenrod, rugosa rose, bayberry, beach plum, black pine, shore juniper

Inter Dune (somewhat protected from salt spray)
beach grass, beach pea, dusty miller, seaside goldenrod, beach heather, rugosa rose, bristly locust, bayberry, beach plum, shore juniper, Japanese black pine, sweet fern, autumn olive, and Virginia creeper

*note: beach pea, bristly locust, bayberry and sweetfern will fix nitrogen from the air and incorporate it into the soil for plant use.

High Dune (exposed to salt spray, drying winds)
Beachgrass

Maritime Forest (protected by high dune)
Beachgrass, beach pea, dusty miller, seaside goldenrod, beach heather, rugosa rose, bristly locust, bayberry, beach plum, Japanese black pine, sweet fern, autumn olive, staghorn and smooth sumac, honeysuckle, american holly, sassafras, black cherry.

Back dunes - include stands of Pitchpine.

Establish the aforementioned plant material by using healthy transplanted material (either taken from existing stands or purchased and set-out for a period of one year prior to planting).

Transplant in April, May or early June and set out on 4'x4' spacing in areas where grass is well established. (grass protects young plants from cutting action of blowing sand).

The use of mulch (wood chips, salt marsh hay or seaweed) will aid in planting success)

Maintain plantings by fertilizing with complete fertilizer as recommended for existing vegetation and beach grass.

Situation: Eroding Bluff

Site Conditions: Glacial till with clay lenses (seeps), droughthy infertile sand, subject to attack by winter storm waves, salt spray, 25-60 feet in height.

Treatment Techniques:

Divert Surface Runoff Away From Lip Of Bluff To A Protected Outlet

- Install minor structural measures such as diversions, 'french' drains or perforated pipe.

Protect Outlets Of Existing Drains On Bluff Face

- Employ rock rip rap, asphalt or other material.
- Insure use of water tight pipe couplings on outlet pipe.

Protect Base Of Slope From Undercutting Due to Wave Action

- Consider major structural means.
- For temporary basal protection, establish plant materials (beach grass, beach pea) within the beach face. Planting establishment will be dependent upon at least one year of non-disturbance. (Basal protection will effect the life expectency of vegetative protection established on the slope face; without adequate basal protection, life expectency of plantings on upper areas is short).

Vegetatively Stabilize Slope Face

- Plant entire area with beach grass or
- Place and anchor jute netting horizontally across slope face for entire area.
- Seed all denuded areas to weeping lovegrass at rate of 5 lbs./acre or 0.1 lbs./1000 sq. ft. during period between May 1st and June 15th only. Annual rye grass may be added to seed requirement)
- Fertilize seeding and existing vegetation with 10-10-10 analysis fertilizer at rate of 800 lbs./acre or 20 lbs./1000 sq. ft.
- Establish the following plant materials in horizontal bands (across slope):

  bristly locust, rugosa rose, autumn olive, japanese bamboo, sweet fern and phragmites. (establish japanese bamboo and sweet fern through use of root cuttings. Phragmites is adapted to sweep areas along clay layers)
- Plant on 2'-4' centers during May and early June (for best results use healthy transplanted material; nursery stock having been previously transplanted for a period of a year or two.)
- Maintain plantings by fertilizing with 10-10-10 analysis fertilizer at rate of 800 lbs./acre and preventing foot traffic upon planted areas. (a split application of 400 lbs. in Spring and 400 lbs. in Fall is good also)

Attachment: "Sources of Supply"

By: Arnold C. Lane, Regional Extension Sea Grant Specialist
Cape Cod Extension Service, Barnstable, Mass.

Bud Reese, Coordinator, The Pilgrim Resource Conservation and
Development Area Office, USDA, Soil Conservation Service, Wareham, Mass.

Richard J. DeVergilio, Soil Conservationist, USDA, Soil Conservation Service
Yarmouth Port, Ma.

Plant Materials

Common Name	Scientific Name	Sources
Japanese Black Pine	Pinus thumbergii	1,2,9,16,17,18,19, 23,26,28,31,32,35,43
Autumn-Olive 'Cardinal'	Elaeaguus Umbellata	1,2,3,5,7,12,13,15, 16,18,25,30,31,35,42, 43
Bayberry	Myrica Pensylvanica	6,7,19,31,32
Bristly Locust "Arnot"	Robina fertilis	1,15,16,29
Beachplum	Prunus maritima	6,19
Rugosa Rose	Ruga Rugosa	6,9,10,13,15,16,17, 18,19,30,31,43
Sweetfern	Comptonia peregrina	14
Shore juniper "Emerald Sea"	Juniperus conferta	44,45,46
Virginia Creeper	Parthenocissus quinquefolia	10,11,18,19,31,32,42
American Beachgrass	Ammophila breviligulata	13,14,16,33,35,38,50
Weeping Lovegrass	Eragrostis curvula	1,3,7,9,11,12,21,24,25 29,36

SECTION C

UNITED STATES FISH AND WILDLIFE SERVICE AND MASSACHUSETTS MARINE FISHERIES

SECTION C

UNITED STATES FISH AND WILDLIFE SERVICE

AND MASSACHUSETTS MARINE FISHERIES

TABLE OF CONTENTS

INTRODUCTION

A meeting was held at Cape Cod National Seashore office on August 1978 with representatives of the U.S. Fish and Wildlife Service, Massachusetts Marine Fisheries, National Park Service and Corps of Engineers. The purpose of the meeting was to discuss the proposed considered plans of improvement and other nonstructural alternatives that will be considered along the Cape Cod shoreline. This appendix includes letter reports and comments on the proposed improvements.

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
ECOLOGICAL SERVICES
P. O. BOX 1518
CONCORD, NEW HAMPSHIRE 03301

August 28, 1978

Colonel John P. Chandler
Division Engineer
New England Division, Corps of Engineers
424 Trapelo Road
Waltham, Massachusetts 02154

Dear Colonel Chandler:

This is our Planning Aid Report on the Easterly Shores of Cape Cod Beach Erosion Study, Cape Cod, Massachusetts.

We understand the project area to encompass the easterly shores from near the Provincetown-Truro town line to south of Chatham. Structural methods of erosion control are being considered from near the Provincetown-Truro town line to south of Nauset Light. From this point south to the Chatham area, structural and non-structural methods are proposed.

Habitat types within or adjacent to the project area include various wetlands, dune grass areas, shrub areas, open fields, and upland woods. Wetland types would include coastal shallow fresh marsh, coastal deep fresh marsh, coastal open fresh water, coastal salt meadows, regularly flooded salt marshes, and sounds and bays.

Vegetation of the freshwater wetlands would consist of grasses, sedges, and other marsh plants such as cattails and smartweeds. Cordgrass, high-tide grass, sea lavender, and glassworts would vegetate the saline wetland areas. Beach grass and beach heather are plants of the sand dunes. Vegetation of shrub areas would include highbush blueberry, swamp azalea, and sweet pepperbush, while various grasses would inhabit open fields. Pitch pine and bear oak are the species which predominate within the upland woods.

Bird species within the project area would include great black-backed and herring gulls, common, arctic, roseate, and least terns, and various shorebirds such as sandpipers, plovers, dowitchers, and the dunlin. Waterfowl, including black ducks and Canada geese, upland game birds such as bobwhite, woodcock, and mourning dove, and various songbirds would also be observed.

Mammals inhabiting the project area would include squirrels, rabbits, mice, deer, opossum, raccoon, skunk, weasels, bats, and foxes.

Finfish and shellfish resources of the project area are numerous. Winter flounder is the most important finfish species within both the offshore and Pleasant Bay areas. Other offshore finfish species include windowpane and yellowtail flounder, skate, spiny dogfish, ocean pout, and Atlantic cod. Species of the Pleasant Bay complex are Atlantic silverside, mummichog, sticklebacks, American eel, longhorn sculpin, sea raven, Atlantic tomcod, blueback herring, alewife, and striped bass. Shellfish species inhabiting the offshore areas are the surf clam and sea scallop. The oyster, bay scallop, quahaug, soft-shelled clam, and mussel are shellfish species of the Pleasant Bay complex.

Endangered fauna of the project area include the bald eagle and the peregrine falcon which migrate through the Cape Cod area. Endangered whale species, including the right, sei, blue, finback, humpback, and sperm whale, are found in offshore areas of the Cape. The endangered hawksbill, leatherback, and Atlantic ridley turtle could also be located offshore of the Cape. While there has been no record of an Eskimo curlew sighting on the Cape since 1913, it is possible that this endangered bird species might be in the Cape Cod area.

Structural methods of erosion control, such as breakwaters, stone mounds, concrete/rubble mounds, rock revetment, and groins and/or sandfill would disrupt wave action and sand transport within the project and adjacent areas. This disruption would have primary and secondary effects on adjacent coastal areas. Sand or rock fill placed in wetland areas would destroy them and their associated fish and wildlife resources. Dredging, depending on the location and time of year, could disturb or destroy benthic organisms, shellfish beds, and finfish species. Beneficial effects of these structures would be in providing habitat for certain finfish species and fowling communities consisting of algae, barnacles, sponges, mussels, amphipods and bacterial slimes. In addition, these structures might provide roosting and nesting sites for certain bird species.

Proposed structural and non-structural methods of erosion control from Nauset Light south to Chatham consist of dune restoration with sand fill, planting of beach grass, placement of snow fences, and controlled public access. Planting of beach grass would provide habitat for certain species of small mammals, and dune restoration on Nauset Beach spit would provide protection for the numerous shellfish beds in Pleasant Bay. Dredging for sand to be used in dune restoration might disturb or destroy benthic organisms, shellfish beds, and finfish species; this would depend on dredging site location and time of year. Controlling public access in certain areas would protect fragile types of habitat.

We understand that the National Park Service is in favor of non-structural methods of erosion control for their property within the project area. This would entail planting of beach grass, placement of snow fences, and controlled public access.

Non-structural methods of erosion control would be the least destructive to fish and wildlife resources. We, therefore, would favor the non-structural methods of planting of beach grass, placement of snow fences, and controlled public access within the project area.

Please keep us informed of any further project developments.

Sincerely yours,

Gordon E. Beckett

Gordon E. Beckett
Supervisor

The Commonwealth of Massachusetts
Division of Marine Fisheries
~~Leverett Saltonstall State Office Building~~
~~100 Cambridge Street Boston 02202~~

Allen E. Peterson, Jr
Director

18 Heritage Professional Building

Rt. 6A, RFD 1, Sandwich, MA 02563

October 5, 1978

Mr. Thomas Bruha
U.S. Army Corps of Engineers
424 Trapelo Road
Waltham, MA 02154

Dear Tom:

In regards to our telephone conversation relative to the breakthrough which occurred at Coast Guard Beach, I must concur with your idea of diking the area as a preventative measure against future similar occurrences. However, the only method I would consider at this time would be the building of an artificial dune anchored with supplemental plantings of beach grass (Ammophilia breviligulata).

If a permanent break occurred in this area there is the possibility of several detrimental changes which may occur in the estuary which I wish to bring to your attention:

1. The Eastham Dept. of Natural Resources is currently utilizing the warm inshore waters of Salt Pond for an experimental shellfish hatchery. A severe influx of cooler Atlantic water could have deleterious effects on this program.

2. A substantial increase in the flushing rate brought on by a break in the barrier beach could hamper the setting rate of the shellfish larvae indiginous to the inner estuary.

3. There now exists commercial densities of soft shelled clams on the inside of the barrier beach. A washover could exterminate this shellfish bed by depositing sufficient quantities of sand over the beds. This causing an economic hardship to the commercial license holders of the Town of Eastham.

I hope these points have shed some light on potential problems if a major breakthrough occurs in this area.

Yours truly,

David L. Chadwick

David L. Chadwick
Assistant Marine Fisheries Biologist

cc: Henry Lind, Town of Eastham

SECTION D

MEETINGS

SECTION D

MEETINGS

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INTRODUCTION

Throughout the course of this study effort, we have held a series of meetings with representatives of involved and interested Federal and State organizations. An initial-stage public hearing was held on 28 November 1973 to obtain the views and comments of all affected individuals and organizations. The comments from this meeting were favorable and a brief summary of the meeting and a list of persons that attended are included in this section. Informal workshop meetings and discussions were held since this initial public meeting with National Park Service personnel, town selectmen and interested local organizations. The following is a list of meeting dates and a brief summary of the meetings. Not included in this section are the meeting dates of the informal visits with Park Service officials and other Federal personnel.

PUBLIC MEETING SUMMARY

A meeting with representatives of the National Park Service and Massachusetts Coastal Zone Management personnel was held 6 April 1977. The purpose of the meeting was to discuss the progress of the report and to advise everyone of the direction to be taken in developing the final report.

Personnel of the New England Division of the U.S. Army Corps of Engineers officials held meetings with the following towns to discuss the Cape Cod Easterly Shores Beach Erosion Control Study:

Town	Meeting Date
Provincetown	4/20/77
Truro	4/21/77
Wellfleet	4/21/77
Eastham	4/20/77
Orleans	4/21/77
Chatham	4/22/77

On 14 August 1978 a meeting was held with the National Park Service, United States Fish and Wildlife Service and Massachusetts Marine Fisheries at the Park Service office in South Wellfleet. At this meeting the proposed plans of considered improvement were presented and discussed in detail. It was requested that the United States Fish and Wildlife Service and Massachusetts Marine Fisheries representatives provide input for enclosure in the final report. Their input was received and is included in Section C of this appendix.

Additional meetings, telephone conversations and pertinent correspondence were undertaken throughout the study and appear in other sections of this appendix.

PUBLIC MEETING

BEACH EROSION CONTROL STUDY
FOR THE
CAPE COD EASTERLY SHORE
CAPE COD, MASSACHUSETTS
HELD 28 NOVEMBER 1973

A public meeting was conducted on Wednesday, 28 November 1973, to discuss the Beach Erosion Control Study for the Cape Cod Easterly Shores, Cape Cod, Massachusetts. Colonel John H. Mason, Division Engineer, U.S. Army Corps of Engineers, conducted the meeting which was held at the Eastham Town Hall, Eastham, Massachusetts. Cecil E. Wentworth and Thomas Bruha represented the Beach Erosion Unit of the U.S. Army Corps of Engineers.

The minutes of the meeting are too lengthy to include in this report. However, the statement by Leslie P. Arnberger, Superintendent of the Cape Cod National Seashore, a telegram from Senator Edward M. Kennedy, and a synopsis of the comments from representatives of the towns involved and from other interested individuals are presented. The attendance list is also included.

STATEMENT BY LESLIE P. ARNBERGER
NATIONAL PARK SERVICE

I am Leslie P. Arnberger, Superintendent of the Cape Cod National Seashore, speaking on behalf of the National Park Service, which is an Agency of the United States Department of the Interior. As a preface to my remarks regarding the proposed erosion study, it should be stated for the record that the Cape Cod National Seashore was authorized by an Act of Congress of August 7, 1961. In its administration of the Seashore, the National Park Service must conform to that Congressional Enactment and to such other legislation as is applicable to the management of the National Park System.

The entire stretch of shoreline to be studied under this project is located within the boundaries of the Cape Cod National Seashore. However, while the majority of the shoreline is in Government ownership, there are substantial sections in town and private ownership as provided under the terms of the [authorizing] legislation for the National Seashore. Furthermore, the submerged lands within one quarter of a mile offshore, are in the ownership of the Commonwealth of Massachusetts with the exception of those submerged lands in Truro and Provincetown conveyed to the United States by the Commonwealth.

The Cape Cod National Seashore is one of our country's most significant coastline areas now receiving more than five million visits annually from people throughout our nation. In its management of the area, the National Park Service is concerned with the preservation of open space and beauty, with the preservation of the natural and historic features and providing for their enjoyment by people now and in the future. This is particularly true of the beaches themselves where our efforts are directed toward the continuation of a quality national environment for appropriate public use. This is a considerably different objective from what usually prevails on privately owned developed shorelines where protection of high-value waterfront property is a prime consideration.

Basic to the accomplishment of the resource management objectives of the Seashore is a detailed knowledge of the natural processes and systems which created and shape the Cape Cod environment. It was with the objective of gaining a better understanding of one of these natural processes, shoreline erosion, that the National Park Service joined with the Selectmen of the lower Cape towns in 1970 in requesting a study by the Corps of Engineers. Hopefully, the information gained from such a study will be helpful, not only to the Park Service but to the towns and the public at large, in planning our activities - and, when I say ours, I mean all of our activities on Cape Cod - more in harmony with the forces of nature.

Recently, there has been considerable publicity regarding a "new" National Park Service policy on beach erosion. This stems largely from the experience of the Service at Cape Hatteras National Seashore in North Carolina. There, for many years, the service expended much effort and money in attempting to "hold the line" on beach erosion through the construction of artifical dunes

and more recently by other measures, including various structures and beach nourishment. These measures have not been successful over the long run and in fact, have contributed to a narrowing of the beach, itself. In view of this experience and the observation that similar beaches in the same area have suffered less damage when left to nature, the decision was reached to abandon these costly and futile attempts to stop natural beach erosion at Cape Hatteras. This, very briefly, is the background for the so-called "new" policy you have heard about recently. Fortunately, at Cape Cod we have not become involved in any really major efforts to stop beach erosion so the so-called "new" policy is really pretty much along the lines of what we have been doing here from the beginning. We did, of course, undertake a very small project at Coast Guard Beach in an attempt to slow down the shoreline recession to prolong the life of the recreational facilities installed at that beach. We may have gained a few years, but in turn a hazardous and unsightly situation has resulted. Had we been more knowledgeable about the natural shoreline processes on Cape Cod and had there been no other conditions to consider in the early '60s when that decision was made, this situation might have been avoided. A detailed professional study of shoreline erosion processes should provide solid scientific data to assist us to work in harmony with the forces of nature rather than to become involved in ill-advised and costly attempts to interfere with the natural systems upon which the continuing quality of the Cape Cod environment depends.

Coastal erosion, as all of you know, has been a fact of life on Cape Cod from the beginning. It troubled those who were here before us, and it will trouble those who come after us. It seems unlikely that mankind will ever totally give up trying to control the forces of nature. This being the case, we should have the very best information possible upon which to base decisions. Hopefully, this study of beach erosion along the backshore by Corps of Engineers will produce objective and unbiased information as a guide to decisions in the future. It is in this spirit and context that the National Park Service looks forward with interest to the finding of the study.

The stretch of shoreline to be studied is among the most precious and fragile of our nation's coastal areas. Its scenic, scientific and historic resources, as well as the opportunities it affords for appropriate forms of public use, are of national significance. It was in recognition of this significance that the area was accorded National Seashore status by Act of Congress. Therefore, it follows that this study and any recommendations stemming from it must fully recognize and be consistent with the special nature and purposes for which this area is dedicated.

It is essential that these factors be reflected in the Environmental Impact Statement and during the course of the project, itself. The National Park Service will be pleased to cooperate with the Corps of Engineers in achieving this objective.

DIGEST OF PUBLIC MEETING

Speaker	Interest Represented	Comments
Colonel John H. Mason Divison Engineer	New England Division U.S. Army Corps of Engineers	Introduced members of his staff. Explained purpose of meeting. Summarized development of a study and procedures involved. Explained speaking procedure for meeting. Later summarized study of Gay Head Cliffs. Mentioned difficulty in maintaining snow fences when people destroy them.
Cecil Wentworth Chief, Beach Erosion Unit	U.S. Army Corps of Engineers	Described study area in terms of area, tidal history, and processes to be studied. Mentioned effect of beach erosion control statutes, percentage of federal funding available to various types of projects.
Fred A. LaPiana, Jr. Selectman	Town of Eastham	Mentioned lack of accurate, complete scientific study of erosion on east shore, dependence of Cape economy on shores and the need for preservation and an end to exploitation. Anticipates breakthrough near the Coast Guard Station very soon. Hopes that study is not already too late.
Joseph L. Silansky North Eastham	Himself	Has lost 47 to 50 feet of his front beach since he moved to North Eastham in 1956, 17 years ago. Suggested snow fences along bottom of [dunes], 1000-foot breakwaters every 200 feet. Reported waves 12 to 14 feet high during northeasters in 1971.

Speaker	Interest Represented	Comments
Stephen R. Perry Selectman	Town of Truro	Favors the study. Concerned about Pamet River which runs within 100 feet of the backshore. Reported that [waves] had broken through twice within the last year [1972]. Reported that Thomas Kane, Chairman of Pamet Harbor Committee, and his committee favor the study. Committee hopes study could include western shore.
Irving A. Horton Selectman	Town of North Truro	Supported Mr. Perry's statement. Favors the study. At end of meeting asked about control of Pamet River valley if seas wash over federally owned lands to spoil town lands in the valley.
Paul P. Hanson, Jr. Chairman, Board of Selectmen	Town of Orleans	Supports the study. Stated that nothing should be done until we know what to do, and a complete study of processes has been made. Mentioned that Cape was fortunate that not many houses were built right on the beachfront, so that "the orderly retreat of the shorefront so far has caused little hardship to any person. But we are getting to the point where it is going to." Stated that preservation of one area should not be at the expense of another. Referred to study of Nauset Harbor where plans yielded a cost-to-benefit ratio of less than one, and the Pleasant Bay study that had a favorable ratio.
Edward T. Harrington Chairman, Board of Selectmen	Town of Chatham	Having no prepared statement, chose to rest on Mr. Arnberger's statement. Reported that the Board of Selectmen of Chatham favor and support the proposed study.

Speaker	Interest Represented	Comments
Marion Perry Selectman	Town of Provincetown	Favors the study. Mentions 30- to 35-year old erosion problem in Provincetown where "high road" was used during high tides and "low road" was used during low tides; high road is gone now.
Howard R. Dykeman Chairman, Board of Selectmen	Town of Wellfleet	Reported that the Board of Selectmen of Wellfleet favors the study.
Richard M. Plante Executive Secretary	Town of Wellfleet	Agreed with Mr. Dykeman.
Barbara Fegan South Wellfleet	Herself	Congratulated Corps on open planning effort. Praised Corps for its "commitment to professionalism." Expressed concern over cost ($500,000) of study when Cape may be gone in 4000 years anyway as compared with $30,000 being spent by Department of Interior on a computer model of the Cape's water supply that might be available for decision making in 3 years. Recommended "a very careful consideration of non-structural beach erosion control measures - things like limited access, increased vegetation," Suggested development of an on-going citizen's advisory group.
Dr. Graham Giese	Marine Consulting Associates North Truro	Questioned funding process. [It was explained by Colonel Mason.] Expressed concern over remarks by previous speakers who assumed that there was very little factual data concerning shoreline erosion, shoreline processes, and shoreline changes on outer Cape Cod. Referred to 1833 studies of Major Graham,

Speaker	Interest Represented	Comments
		Henry Marindin's extensive survey [1891], and studies supported by Office of Naval Research and carried out by the Coastal Studies Group at Woods Hole Oceanographic Institution between 1953 and 1960. Mentioned he was a member of that group.
Mrs. F. C. Bragg Dennis Port	Herself	Found everything she had to say had already been well said.
John B. Lucke Harwich Port	Himself	Agreed with Mrs. Bragg.
Fay Ann Shook North Eastham	Herself	Stated that for 24 years her family had owned land next to Nauset Lighthouse. Has noticed increased erosion since the park became a park. Noted that protecting one area without protecting adjacent ones eventually causes erosion of protected area anyway. Asked if anything could be done to control pedestrian traffic on the cliff faces.
Mirian Rowell Eastham	Cape Cod Bird Club	Expressed great concern for nesting colonies of terns both within and outside the Park. Recommended contacting the Tern Warden of Cape Cod National Seashore Park and the Massachusetts Audubon Society.
Roy B. Meservey, Jr. Chatham	Chatham JCs	Favors the study.
Paul Hanson Orleans	Himself	Questioned why Monomoy Island had been left out of the study. [Mr. Wentworth explained that the study was originally established

Speaker	Interest Represented	Comments
		to consider area within the Cape Cod National Seashore but that areas adjacent to it will be evaluated.]
Letter from Richard E. Griffith Regional Director	Department of Interior Fish and Wild Life	Received notice of this meeting but current staff commitments prevent attendance. Requested copy of minutes.
Dr. Benno Brenninkmeyer, S. J. Department of Geology and Geophysics Boston College	Himself	Questioned methods to be used during study.
Philip Schwind Shellfish Conservation Agent Eastham	Himself	Questioned whether areas taken for conservation restrictions are considered private property or conservation areas.
Mrs. E. H. Steif Chatham	Herself	Asked when recommendations based on the study will be made.
Brenda Bohlen Brewster	Herself	Questioned cost and length of time for study. Suggested that literature search be made and used. Asked if literature search is made before a study cost is estimated.
Jay Leonard Bolt, Beranek & Newman Cambridge, Mass.	Himself	Asked if a plan of study or research document explaining study technique would be prepared and, if so, would it be made public prior to the commitment of the study.

ATTENDANCE LIST

PUBLIC MEETING CONDUCTED 28 NOVEMBER 1973
EASTHAM TOWN HALL
EASTHAM, MASSACHUSETTS

Leslie P. Arnberger
Cape Cod National Seashore
South Wellfleet, Mass.

Mike Bean
Nauset Road
Eastham, Mass.

Norton M. Bean
Nauset Road
Eastham, Mass.

Claire A. Berger
21 Court Street
Provincetown, Mass.

Mrs. John Bihacke
15 Pleasant Street E-24
Harwich Port, Mass.

Mr. & Mrs. Robert A. Bohlen
Eddwood Road
No. Eastham, Mass.

Brenda J. Boleyn
Freeman's Way
Brewster, Mass.

Prof. & Mrs. F. C. Bragg
P. O. Box 966
Dennis Port, Mass.

Dr. Benno Brenninkmeyer, S. J.
Department of Geology
and Geophysics
Boston College
Chestnut Hill, Mass.

Marion & Howard E. Brewer
Nauset Road
Eastham, Mass.

William F. Calvin
Box 9
South Wellfleet, Mass.

Mr. & Mrs. William Coe
6 Great Oak Road
East Orleans, Mass.

Mr. & Mrs. Kenneth Cole
Paine Hollow Road
South Wellfleet, Mass.

Robert L. Deschamps
Eastham, Mass.

Malcolm M. Dickinson
Freeman Lane
Orleans, Mass.

G. O. Duffy
R.R. 1
Eastham, Mass.

C. P. Ehrhardt
P. O. Box 195
Eastham, Mass.

Barry D. Eldredge
Box 364
Chatham, Mass.

Maureen Formenter
School Street
W. Dennis, Mass.

Barbara Fegan
Box 545
South Wellfleet, Mass.

Dr. Graham. S. Giese
Box 154
Provincetown, Mass.

Raymond Gowdy
35 Freeman's Way
Brewster, Mass.

Gary Guentin
50 Hazel Street
Attleboro, Mass.

Edward T. Harrington
Old Harbor Road
Chatham, Mass.

Joyce Hartson
Route 6
North Eastham, Mass.

Jeffrey A. Haulick
Depot Road Box 39
Eastham, Mass.

Paul P. Henson, Jr.
Box 707
Orleans, Mass.

W. D. Hess
58 Riverview Drive
Chatham, Mass.

Mr. & Mrs. Earle F. Hiscock
Old Harbor Road
No. Chatham, Mass.

Robert Holmes
Route 6
North Eastham, Mass.

Irving A. Horton
Route 6A
North Truro, Mass.

Howard W. Irwin
P. O. Box 1
Eastham, Mass.

Dr. & Mrs. Robert F. Jammison
Chequesset Neck Road
Wellfleet, Mass.

William P. Jensen
Box 625
So. Wellfleet, Mass.

Howard R. D. Keman
Connon Hill Road
Wellfleet, Mass.

E. S. Kerfoot
P. O. Box 908
Orleans, Mass.

Fred A. LaPiana, Jr.
Nauset Road
Eastham, Mass.

Jay Leonard
Bolt, Beranek & Newman
50 Moulton Street
Cambridge, Mass.

Alison Lotter
Route 6
Eastham, Mass.

Alfred L. Lotter
Route 6
Eastham, Mass.

Wayne V. Love
67 Eldredge Sq.
P. O. Box 395
Chatham, Mass.

John B. Lucke
15 Pleasant Street
Harwich Port, Mass.

Claude W. Lumpkin
78 Hitching Post Road
Chatham, Mass.

Gladys G. Lumpkin
78 Hitching Post Road
Chatham, Mass.

Karyn Martin
Box 33
Truro, Mass.

Mrs. L. D. Maza
Portanimicut Road
So. Orleans, Mass.

Leonard D. Maza
Box 56
So. Orleans, Mass.

Jay W. Mead, Jr.
Great Pond Road
Eastham, Mass.

Peter J. Meize
Route 6
Eastham, Mass.

Roy B. Meservey, Jr.
Malabar Road
Chatham, Mass.

Paul R. Mices
50 Moulton Street
Cambridge, Mass.

Ganja Nelson
Route 6
North Eastham, Mass.

Isabel F. Nickerson
100 Old Academy Road
Chatham, Mass.

Rilal O. Penny
Route 6
Eastham, Mass.

Marion Perry
25 Standish Street
Provincetown, Mass.

Stephen R. Perry
Perry Road
Truro, Mass.

Mrs. John A. Phillips
Kingsbury Beach Road
Eastham, Mass.

Richard M. Plante
Cove View Road
Wellfleet, Mass.

La Rowell
Nauset Light Road
Eastham, Mass.

Miriam L. Rowell
Nauset Light
Eastham, Mass.

Phil Schwind
Somoset Road
Eastham, Mass.

Robert Seay
Box 16
Eastham, Mass.

Fay Ann Shook
County Road
North Eastham, Mass.

Joseph L. Silansky
115 Riverview Drive
Chatham, Mass.

Colin E. Stewart
Christian Science Monitor
Boston, Mass. 02115

William M. Sullivan
Nauset Road
Box 575
North Eastham, Mass.

Tom Swan
R.R. 1
Eastham, Mass.

Donald A. Verfaillie
Kingsbury Beach Road
Eastham, Mass.

Roland Verfaillie
Kingsbury Beach Road
Eastham, Mass.

Dr. & Mrs. H. E. Whitlock
P. O. Box 325
Eastham, Mass.

Gordon R. Whittum
Foxwood Drive
Eastham, Mass.

Gilbert D. Williamson
Oak Lane
Box 655
Eastham, Mass.

Albert S. Young
Orleans Road
Chatham, Mass.

Mrs. Albert S. Young
Orleans Road
Chatham, Mass.

SECTION E

REPORTS

INTRODUCTION

Over the years several reports on the outer Cape have been completed or are currently underway. The following table indicates these reports and their status.

REPORTS

Title	Agency*	Status	Published
Pleasant Bay, Massachusetts	NED*	Complete 1970	H.D. No. 91-430
Shore of Cape Cod between the Cape Cod Canal and Race Point, Provincetown, Massachusetts Beach Erosion Control Study	NED*	Complete 1960	H.D. No. 404
Shoreline changes along the outer shore of Cape Code from Long Point to Monomoy Point.	NED*	Complete 1978	CRREL Report 78-17
Chatham Bars Inlet	NED*	To be re-leasted in 1979	-
Beach Evaluation Program on Cape Cod	CERC*	Draft Review	-
Beach Evaluation Program on Cape Cod	CERC	Unknown	-
A preliminary Report on the Application of commercially available radar for the determination of wave direction	CERC	Unknown	-

*NOTE:

NED - New England Division, Corps of Engineers, Waltham, Massachusetts
CERC - Coastal Engineering Research Center Fort Belvoir, Virginia

INTRODUCTION

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CERC - Coastal Engineering Research Center Fort Belvoir, Virginia

SECTION F

ARCHITECT ENGINEER CONTRACTS

SECTION F

ARCHITECT ENGINEER CONTRACTS

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INTRODUCTION

During the course of the study the Corps decided to engage the services of several consulting engineering firms knowledgeable in various technical aspects of the report to expedite the completion of the report. The following is a list of engineering firms that were contracted or contributed to the report.

Firm	Contract No.	Title	Status
Analysis & Technology, Inc.	DACW 33-78-C-0022	Shoreline Changes	-
EG&G International Inc.	DACW 33-76-C-0131	Land Use	Included in Final Report
University of Rhode Island	DACW 33-76-M-0446	Wave refraction analysis	Summarized in Final Report
U.S. Army Cold Regions Research and Engineering Laboratory		Shoreline Changes along the Outer coast of Cape Cod	Summarized in Final Report

SECTION G

PERTINENT CORRESPONDENCE

SECTION G

PERTINENT CORRESPONDENCE

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Town of Eastham

BOARD OF SELECTMEN
BOARD OF ASSESSORS

BOARD OF HEALTH

Eastham, Massachusetts 02642

December 16, 1969

Representative Hastings Keith
House of Representatives
Capital Buildings
Washington, D. C.

Dear Congressman Keith:

On Friday, December 12, 1969 an article appeared on the front page of the Cape Cod Standard Times, a copy of which is enclosed. Naturally, we view this project with great interest because we see our historic "outer beach" as one of the best and most vital in the country.

In the past we have tried in vain to obtain any information whatsoever from the Army Corps of Engineers about this type of project. Frankly we are quite dismayed and disappointed to see that we have been overlooked.

Perhaps with your assistance we can initiate action on this project. Of course you are aware that this area is within the boundaries of the Cape Cod National Seashore, but is still privately and town owned. We have no intention of circumventing the Seashore and we would appreciate their cooperation and assistance in this matter.

May we hear from you with regard to this subject?

Sincerely,

Luther P. Smith, Chairman

Prescott B. Cummings

Prescott B. Cummings

Fred G. LaPiana, Jr.

Board of Selectmen

es
enc.

12TH DISTRICT, MASSACHUSETTS

WASHINGTON TELEPHONE:
AREA CODE 202: 22[illegible]-3111

DISTRICT OFFICE:
243 POST OFFICE BUILDING
NEW BEDFORD, MASSACHUSETTS 02740
993-7393

Congress of the United States
House of Representatives
Washington, D.C. 20515

INTERSTATE AND FOREIGN
COMMERCE

COMMITTEE ON
MERCHANT MAR[illegible] AND
FISHERIE[illegible]

January 2, 1970

Colonel Frank P. Bane
Corps of Engineers
Department of the Army
424 Trapelo Road
Waltham, Massachusetts

Dear Colonel Bane:

I recently received the enclosed letter from the Town of Eastham Selectmen expressing a desire to have the Corps conduct a beach erosion study of their beaches.

Apparently, the success that we had with the Barnstable request has given them the impression that they were overlooked. I would very much appreciate it if your office would contact the Eastham Selectmen and give them any assistance possible. Since Eastham's beaches are within the Cape Cod National Seashore, it would seem appropriate to contact Superintendent Arnberger for his views on the matter.

Your assistance in this matter will be very much appreciated.

Sincerely,

Hastings Keith

HASTINGS KEITH
Member of Congress

HK:lsp

NEDED-R 26 January 1970

Honorable Hastings Keith
House of Representatives
Washington, D. C. 20515

Dear Mr. Keith:

This is in reference to your letter of 2 January 1970 inclosing a letter from the Board of Selectmen, Town of Eastham, Massachusetts requesting your assistance in initiating a beach erosion study for the town's beaches.

As discussed with you, town of Eastham officials, and a representative of the Cape Cod National Seashore at your seminar in Plymouth, Massachusetts on 16 January 1970, erosion processes on the Atlantic Ocean side of Cape Cod, that is the eastern exposure, are very complex and variable. To properly evaluate the problem, a study of the entire eastern side of the outer arm of Cape Cod extending from Provincetown to the southern extremity of Nauset Beach would be required. Most of the shorefront involved is owned by the Cape Cod National Seashore. The remaining shorefront is owned in part by the Towns of Chatham, Orleans, Eastham, Wellfleet, and Truro and by private interests. It was the view of the Cape Cod National Seashore representative that, if all the concerned towns desire a beach erosion control study be made by the Corps of Engineers of the shorefront indicated above, the National Park Service would cooperate in any way possible in the study. If the towns involved and the Cape Cod National Seashore are in mutual agreement that a beach erosion study should be made to determine whether erosion control measures are needed and justified, such a study could be obtained by Congressional resolution.

NEDED-R 26 January 1970

Honorable Hastings Keith

*A draft of a suggested resolution, which would be appropriate for submission to the House Public Works Committee, is inclosed. I trust this information is satisfactory to your needs. Please let me know if I may further assist you in this matter. *original has been changed

Sincerely yours,

1 Incl
As stated

FRANK P. BANE
Colonel, Corps of Engineers
Division Engineer

Copy furnished:
Hon. Hastings Keith
243 P.O. Bldg.
New Bedford, Mass. 02740

OCE, ATTN: ENGCW-PD

Copy to:
Mrs. Quill
Mr. Leslie
Mr. Hill
Mr. Arpin
Reading File
Engr. Div. File

DRAFT OF PROPOSED RESOLUTION

Adopted 2 December 1970

Resolved by the Committee on Public Works of the United States House of Representatives, that the Board of Engineers for Rivers and Harbors, created under Section 3 of the River and Harbor Act approved June 13, 1902, be, and is hereby requested to review the report on Land and Water Resources of the New England-New York Region, published as Senate Document Number 14, Eighty-fifth Congress, with a view to determining the need and advisability of providing improvements along the easterly shoreline of the outer arm of Cape Cod extending from Provincetown to the southern extremity of Nauset Beach in the interest of beach erosion control, shore protection, navigation and allied purposes.

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
424 TRAPELO ROAD
WALTHAM, MASSACHUSETTS 02154

IN REPLY REFER TO
NEDED-R

29 October 1973

ANNOUNCEMENT OF PUBLIC MEETING
BEACH EROSION CONTROL STUDY
FOR THE
CAPE COD, EASTERLY SHORES
CAPE COD, MASSACHUSETTS

MEETING TO BE HELD AT 7:30 PM E.S.T.
ON 28 NOVEMBER 1973
IN MEETING ROOM
EASTHAM TOWN HALL
EASTHAM, MASSACHUSETTS

The Congress of the United States has directed the Corps of Engineers to make a Beach Erosion Control Study of the Cape Cod easterly shores, Cape Cod, Massachusetts. The study will be made under authority of a resolution adopted 2 December 1970 by the Committee on Public Works of the United States House of Representatives, which reads as follows:

"Resolved by the Committee on Public Works of the House of Representatives, United States that, in accordance with Section 110 of the River and Harbor Act of 1962, the Secretary of the Army is hereby requested to direct the Chief of Engineers to make a survey of the easterly shores of the outer arm of Cape Cod, Massachusetts, extending from Provincetown to the southern extremity of Nauset Beach, in the interest of beach erosion control, hurricane protection and allied purposes."

In order that the study may be responsive to the desires of affected or interested parties, a public meeting will be held as indicated above. The purpose of this meeting is to exchange information concerning the study, the beach erosion and related problems involved, and possible solutions. A map of the study area is attached. Information is also sought on the ecological and environmental conditions in the area.

The study involves the easterly shore of Cape Cod from Long Point at Provincetown, southerly to the southern tip of Nauset Beach which comprises about 46 miles of shoreline all within the boundary of the Cape Cod National Seashore. The area includes the towns of Provincetown, Truro, Wellfleet, Eastham, Orleans and Chatham. The shoreline is made up of dunes, bluffs and beaches consisting of unconsolidated glacial material, which is easily eroded by storm driven waves, frequently experienced during easterly storms.

The study will provide much useful technical information not now available including: rate of shoreline recession; storm tide level frequency; wave refraction analysis with direction of predominant littoral transport and wave energy. The study will also include the economic and practical feasibility of providing beach erosion control measures with particular emphasis on the environmental effects.

Current beach erosion control statutes authorize Federal participation up to 50 percent of the cost of economically feasible beach erosion control improvements along publicly-owned beaches, up to 70 percent along beaches fronting park or conservation areas that meet certain requirements, and 100 percent along Federal property. Federal participation in the cost of improvements along privately-owned shorefronts can only be made if there are sufficient public use benefits. One of the requirements for Federal financed participation is continued public ownership and public use of the shore during the economic life of a project including free and direct access to the improvement.

All interested parties are invited and urged to be present or represented at this meeting, including representatives of Federal and non-Federal public agencies; agricultural, commercial, industrial, business, transportation, and utilities interests; civic, ecological and environmental, boating, recreation, and fish and wildlife organizations; and interested or concerned citizens, property owners, and other interests. All parties will be afforded full opportunity to express their views and furnish specific data on matters pertinent to the study, including technical, economic, and ecological and environmental material. Statements should be supported by factual information insofar as practicable.

Oral statements will be heard but, for accuracy of record, all important facts and statements should be submitted in writing, in duplicate. Written statements may be handed to the presiding officer at the meeting or may be mailed beforehand to the undersigned at the

NEDED-R 29 October 1973

Corps of Engineers address in the letterhead. Statements so mailed should indicate that they are in response to this announcement. All statements, both oral and written, will become part of the official written record on this study and will be made available for public examination.

Final selection of a plan for recommendation to higher authority will be made only after full consideration is given to the views of responsible agencies, groups, and citizens. However, this cannot be taken as an indication that the Federal government will undertake any improvements or programs. Although the study may result in recommendations for undertakings by the Federal government, their accomplishment would depend upon subsequent authorization and funding by the U.S. Congress.

Please bring this announcement to the attention of anyone you know who is interested in this matter.

John H. Mason

JOHN H. MASON
Colonel, Corps of Engineers
Division Engineer

3 Incls
1. Map
2. Questionnaire
3. Guide Outline for Environmental Data

TELEGRAM FROM
SENATOR EDWARD M. KENNEDY

"Dear Colonel Mason, I am so sorry that I will not be able to attend the open meeting tomorrow on the beach erosion study for the Cape. I want you to know that I wholeheartedly endorse your efforts and assure community participation in this most important program. And I am certain that the residents of Cape Cod will participate in enormous numbers. The New England Division of the Corps has provided an outstanding example to Congress and to the rest of the Nation in developing the Charles River Water Shed Project by working with local residents and officials, and we from Massachusetts are very proud of that project in hearings here in Washington. The reason that the Charles Project is unique and innovative is because of the input of local citizens and the leadership of the Corps. And I know as you move forward with the Cape Erosion Study, you will provide that same leadership. Please keep me posted on the public meeting and meetings. Please let me know if I can be of any assistance to you.
Edward M. Kennedy, USS."

QUESTIONNAIRE

1. State full description of the improvements desired and furnish, if possible, a sketch or map showing their location and dimensions.

2. Furnish any pertinent history relating to erosion problems along the shore including wave processes and other related factors.

3. State any knowledge of land usage and ownership of the shoreline.

4. Furnish any additional information pertaining to needs for coastal water resources development for the area.

5. State what specific benefits may be derived from preservation of the shore, annual visitation, effect on economy of the area as a whole.

6. State what local cooperation such as cash contributions, supplementary improvements by local interests or furnishing of lands, easements and rights-of-way could be expected from local agencies, either public or private, to assist the Federal Government in effecting the improvements desired.

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
424 Trapelo Road
Waltham, Massachusetts 02154

GUIDE FOR PRESENTING ECOLOGICAL AND ENVIRONMENTAL INFORMATION AT PUBLIC MEETING

The United States Congress by the enactment of the Environmental Quality Act of 1969 requires that consideration be given to ecological and environmental conditions and problems related to the area that is being studied for a potential project.

In compliance with the Act the Corps of Engineers must prepare a detailed statement on the environmental aspects of the project.

Prior to the preparation of the Environmental Statement we welcome information and comments from all concerned governmental agencies, organizations, groups and individuals. This information can be presented at the Public Meeting or mailed to the Corps of Engineers, New England Division.

From experience we have found that certain considerations on ecological or environmental matters are usually explored. These are listed. The list is not intended to be all inclusive nor intended to imply that each item applies to your coastal area. The list is provided for your use as a guide only.

1. Generally shellfish, fish, shore birds, waterfowl, and plants are the principal species of concern in coastal projects although consideration is given to all life forms.

   a. What important species are involved?
   b. Recreation or commercial value?
   c. What type of construction activity will affect them? How?
   d. Will any effect be temporary or permanent?
   e. Are there any desirable species (present or absent) that should be encouraged? How?

2. Man's use and enjoyment of the environment is also of concern.

a. What uses are involved?
b. Recreational or commercial value? Other?
c. Aesthetic considerations? Historic? Geologic?
d. Are there any conditions that limit man's use and enjoyment of the area? How?
e. What type of construction activity will improve or interfere with man's use?
f. Will any effect be temporary or permanent?

3. Water quality is important to the natural ecology as well as man's use and enjoyment of the environment.

a. Are there any outfalls or other discharges that may affect water quality? Location? Type of discharge?
b. Will any activity required to effect coastal improvements (such as dredging, filling, disposal of materials, etc.) affect water quality?
c. Will any change in water quality impede marine life by interfering with spawning, migration, nursery/feeding areas, etc.?
d. Will any alteration of water quality affect swimming, fishing (sport/commercial) or any other activity?
e. Will any effect be temporary or permanent?

DAEN-CWP 25 January 1974

Mr. Ronald H. Walker
Director, National Park Service
U. S. Department of the Interior
Washington, D.C. 20240

Dear Mr. Walker:

This is in response to your letter of 28 December 1973 concerning our beach erosion control study for Cape Cod. The study is being made in response to a resolution adopted by the Committee on Public Works on 20 December 1970. A public meeting on the study was held in Eastham, Massachusetts, on 28 November 1973. A National Park Service statement delivered at the meeting supported the need for a study.

The Corps of Engineers would welcome a representative of the Park Service to serve as liaison between the Park Service and the Corps. Such assistance in better communication and coordination between our agencies would help to insure an efficient approach to the study and an examination of the alternatives to find solutions both economically and environmentally acceptable.

It is suggested that a briefing of your staff take place in the office of the New England Division Engineer, Waltham, Massachusetts, in early February 1974. Mr. John C. Housley, Planning Division, Directorate of Civil Works, Washington, D.C. 20314, telephone 202-693-6868, is designated the contact for arranging the briefing.

Sincerely,

J. W. MORRIS
Major General, USA
Director of Civil Works

CF:
New England Division

United States Department of the Interior

NATIONAL PARK SERVICE
WASHINGTON, D.C. 20240

OFFICE OF THE DIRECTOR

DEC 28 1977

Major General J.W. Morris
Director of Civil Works
Office of the Chief of Engineers
Department of the Army
Washington, D. C. 20314

Dear Major General Morris:

We have noted with great interest that the U.S. Army Corps of Engineers is proposing to undertake a coastal zone management study in the area of the Cape Cod National Seashore.

Since the National Park Service has a great interest in this area and since the National Park Service, in addition, has the legislative obligation to conserve and maintain this area unimpaired for the use of future generations, the scope, purpose, and intent of this study is of concern to us.

I would, therefore, appreciate it if you could arrange to have members of my staff briefed on this project and, furthermore, if you would consider appointing a knowledgeable person from the National Park Service to serve as a member of the study team for purposes of establishing liaison between the Service and the Corps.

For the purposes of communicating with this office you may feel free to interact directly with the Chief Scientist of the National Park Service, Dr. Theodore W. Sudia, who may be reached at Room 4125, 1100 L Street, N.W., Washington, D. C. 20240, telephone number 523-5051.

Your early response to this letter will be sincerely appreciated.

Sincerely yours,

Director

United States Department of the Interior

NATIONAL PARK SERVICE

CAPE COD NATIONAL SEASHORE
SOUTH WELLFLEET, MASSACHUSETTS 02663

IN REPLY REFER TO:

D54

April 11, 1977

Mr. Thomas C. Bruha
Chief, Beach Erosion Section
Department of the Army
Corps of Engineers, New England Division
424 Trapelo Road
Waltham, Mass. 02154

Dear Mr. Bruha:

This letter is to confirm our discussions on April 6, 1977 concerning the erosion studies your agency is conducting on the ocean beaches of Cape Cod.

We would certainly appreciate any and all information your studies could provide regarding the history of erosion, rates of erosion, and suggestions for erosion control along the outer beaches of Cape Cod National Seashore. Those areas that are of particular interest to us are as follows: Herring Cove Beach and Race Point Beach in Provincetown, Massachusetts; Head-of-the-Meadow Beach and the Highland Light Area in Truro, Massachusetts; Marconi Station Area and Marconi Beach in Wellfleet, Massachusetts; and Nauset Light Beach and Coast Guard Beach in Eastham, Massachusetts.

Please contact us for any further information you may require regarding Cape Cod National Seashore.

Sincerely yours,

Dan E. Cockrum

Dan E. Cockrum
Acting Superintendent

AMERICAN REVOLUTION BICENTENNIAL 1776 1976

DISPOSITION FORM

For use of this form, see AR 340-15; the proponent agency is The Adjutant General's Office.

REFERENCE OR OFFICE SYMBOL	SUBJECT
NEDPL-C	Workshop Meetings on Cape Cod Easterly Shores Beach Erosion Control Study

TO Division Engineer FROM Project Engineer DATE 24 May 77 CMT 1
Mr. Bruha/bc/554

THRU: Channels

1. On 20,21 and 22 April 1977 Messrs Thomas Bruha and John Sargent of the Planning Division, Coastal Development Branch conducted a series of workshop meetings with the Selectmen of each of the six towns in the subject study area (see attached map, Incl 1). Accompanying them was Mr. James McDevitt, one of the NED photographers. The purpose of the meetings was to inform the town officials of the status of the subject study and to bring them up to date on the procedure that we will be following during the next years, i.e. to time of completion. Prior to these meetings, a a meeting was held with Mr. Hadley, Superintendent of the Cape Cod National Seashore and Mr. Les Smith of the Massachusetts Coastal Zone Management, in Mr. Hadley's office at Wellfleet, informing them of the progress of the report to date and to discuss the needs and desires of the Park Service on critically eroded areas.

2. The workshop meetings were held with the selectmen at the town halls (see attached schedule, Incl 2). We initially planned to include interested citizens or local organizations concerned about the erosion of Cape Cod, but the selectmen of each town decided that the meeting should be held with them and that either they would act as coordinators for their townspeople or they would assign a representative from the town as a contact for future coordination and input to the study. The meetings were scheduled in the morning because the selectmen are part time officials and the morning was convenient for them. This allowed us the afternoon to investigate and photograph the shore. Thanks to the Park Service, which provided us with a vehicle and driver, we were able to photograph and document the configuration of the easterly shore from the southern tip of Nauset Beach to Race Point at Provincetown.

3. Each meeting was attended by at least one selectman and at several of the meetings a representative of a concerned citizen group was present as well as the press. The selectmen were informed of the progress of the report to date and of the direction we were planning to take with the cooperation of the towns and the National Park Service. It is our intention to develop our study and report around the desires and problems that exist in each of the six towns and the Park Service. Therefore, it will be necessary to obtain feedback from them with respect to erosion areas along the shore so that the report can be responsive to their needs. They were asked to submit in writing specific data on problem areas they would like us to discuss in the report. A questionnaire was left with each town to assist us in obtaining specific information for conducting the study (see attached questionnaire, Incl 3).

4. The exchange of information at the workshop meetings was very encouraging. We are hopeful that they will respond with some meaningful information to assist us in developing a report that will reflect the needs and desires of all concerned.

Appendix 4

DA FORM 2496, 1 FEB 63 REPLACES DD FORM 96, EXISTING SUPPLIES OF WHICH WILL BE ISSUED AND USED UNTIL 1 FEB 63 UNLESS SOONER EXHAUSTED.

☆ U.S. GPO: 1974-555-130/9656

NEDPL-C 24 May 1977

SUBJECT: Workshop Meetings on Cape Cod Easterly Shores Beach Erosion Control Study

Based on the information we receive, we are planning on dividing the report into three volumes: Volume I "Main Report"; Volume II "Appendices"; Volume III "Reports on each town and the National Sea Shore ".

5. The selectmen were encouraged by our efforts to keep them informed about the progress of our study, and feel they have useful information that we can use and are willing to cooperate in any way necessary to develop the report.

6. We are planning several other visits to the area during the next several months to follow up our coordination with the towns and to note the seasonal changes as they occur and influence the shoreline processes in the study area.

7. Attached is a copy of a preliminary flow chart (Incl 4) outlining the study procedure that will be used as a guide in writing and coordinating the report.

T.C. Bruha
BRUHA

4 Incls
a/s

cc: Mr. Arpin
Planning Div File

CAPE COD EASTERLY SHORES BEACH EROSION CONTROL STUDY

7 April 1977

MEETING DATES

		4/20 WEDNESDAY	4/21 THURSDAY	4/22 FRIDAY
1.	Chatham - Mr. T. Pennypacker			10:30
2.	Orleans - Mr. Wilcox		9:00 a.m.	
3.	Eastham - Mr. Lapiana, Chairman	10:00		
4.	Wellfleet - Mr. Rockwell		10:30	
5.	Truro - Mr. Brown			9:00
6.	Provincetown - Mrs. Avellar	11:30		

7. National Park Service and Mass CZM held 6 April 1977 at National Park Service Headquarters, Wellfleet (with Mr. Hadley, NPS and Mr. Lester Smith, Mass CZM).

CAPE COD EASTERLY SHORES

BEACH EROSION CONTROL STUDY

WORKSHOP QUESTIONNAIRE

DATE:

BY WHOM:

1. Town:

2. Length of Shoreline (Easterly Shore):

3. Population (Latest Available):

   a. Permanent

   b. Summer

4. Historical Records For:

a. Hurricanes (See Page 6)

Date	Still Water Elevation	Damage Areas (Indicate if Available)			
		Maps	Photos	Surveys	News Clips

B. Northeasters (See Page 6)

Date	Still Water Elevation	Damage Areas (Indicate if Available)			
		Maps	Photos	Surveys	News Clips

Cape Cod Easterly Shores

Beach Erosion Control Study

Workshop Questionnaire

OWNERSHIP:

1. Town:

   a. Location of Shoreline (indicate on map).

   b. Shore Length (approximate)

   c. Ownership — Indicate on Map

      (1) Private ——————
      (2) Public ------
      (3) Federal x-x-x-
      (4) Town o-o-o-
      (5) Other -.-.-.

d. Shore Use
   (1) Private
   (2) Public
   (3) Recreational
   (4) Non-Recreational
   (5) Developed
   (6) Undeveloped

e. Beach width above M.H.W. (Av. in feet)
   (1) Description

f. Backshore
   (1) Description (Bluffs, dunes, roads, developed, undeveloped, etc.)

g. Public Facilities
   (1) Description (See J Below)

h. Protective Structures (groins, rock revetment, timber bulkheads, walls, etc.,) (See K below)
   (1) Description

i. Erosion Areas (See L Below) Indicate on map

(1) Critical //////

(2) Non-critcial #-#-#-

(3) Accretion +-+-+-

j. Public Recreation Area Facilities

(1) Bathhouse

(2) Sanitary

(3) Parking

(4) Picnic Area

k. Structures

(1) Rock Revetment

(2) Groins

(3) Walls

(4) Jetties

(5) Bulkheads

l. Description of Erosion or Accretion

m. Environmental Considerations

n. Improvement Desired

o. Remarks

LIST OF STORM DATES

1976 Feb 2

1974 Dec 2

1972 Feb 19-20

1968 Nov 12

1967 May 26

1966 Jan 30

1963 Nov 30

1962 Mar 7-8

1961 Jan 20

1960 Sep 12 "Donna"

1959 Dec 29

1958 April 2-7

1958 Feb 16-17

1958 Jan 7-8
14-15
21-22

1956 Mar 16-17

1955 Aug 18-19 "Diane"

1954 Sep 11 "Edna"

1954 Aug 31 "Carol"

1953 Nov 7

1953 Apr 13

1952 Feb 28

1950 Sep 11-12

1947 Nov 12

1945 Dec 20

1944 Nov 30

1944 Sep 14

1940 Apr 21

1938 Sep 21

1931 Mar 4

1931 Jan 6

1914 Mar

1909 Dec 26

1851 Apr

1839 Dec 27
Dec 15

1786 Dec 4

1723 Feb 24

1718 Apr 26

1635 Aug 15

The above storm information is to be used as a guide; you may have additional information of other N.E. storms that have caused problems along the easterly shore of Cape Cod. Please feel free to include these or any other storm data as part of your report.

COLGATE UNIVERSITY
HAMILTON, NEW YORK 13346

Department of Geology

August 3, 1977

Mr. Thomas Bruha
U.S. Army Corps of Engineers
424 Trapelo Road
Waltham, Massachusetts 02154

Dear Tom,

I have spent some time thinking about your Provincetown to Nauset Beach study since we talked on the phone early in June. The following outlines my thoughts to date: (1) The waves are a given constant that control the rate of movement of beach material to the northern and southern spits from the cliffed section of the coast. (2) The rate of cliff retreat is controlled by the rate at which the waves remove beach sediments from the base of the cliff, because the beach is renourished to a new "equilibrium" profile by cliff material. (3) Therefore, if one wishes to stop or retard the rate of erosion the wave energy must be reduced and/or the waves must be fed other substituted material to move along the shore. (4) Grain fields may reduce long shore drift and locally broaden the beach but usually at the expense of erosion down drift of the protected area. (5) Shore parallel breakwaters as with grains may protect sections but unprotected areas will erode proportionally faster to supply the waves with sediment to carry along the beach and the protected areas become increasingly more prominent and subjected to the ever increasing energy of refracted waves focussed on the headlands. (6) A nourishment program that would substitute for the nearly 1 meter average annual loss along the length of the cliffs seems costly even if source area, trucks and roads were available. (7) In conclusion it seems to me that the best plan is to accept the nature of the waves, sediment transport, and coastal retreat. Nearshore facilities should be set back from the shore in proportion to their predicted life span or be designed as mobile structures.

The problem of Inlet channel and harbor maintenance or improvement seems equally troublesome for the following reasons. (1) The ocean waves continuously carry sediment to and past any inlet with the longshore drift. (2) The tidal currents, local waves and refracted swell from the ocean carry more sediment into than out of the tidal estuaries causing shoaling within. (3) This reduces the volume exchanged with each tidal flushing and thus the natural entrance will tend to have a lower water velocity and become a depositional area.

I think Willard Bascom's Waves and Beaches, 1964, Anchor Books (S34), Doubleday and Co., Inc., Paul Komar's Beach Processes and Sedimentation, 1976, Prentice Hall and F.P. Shepard and H.R. Wanless' Our Changing Coastlines, 1971, McGraw Hill, substantiate these views and explain in more detail the basis of my thinking.

My plans for the week of August 22 are getting very complex with family and a research cruise in Pleasant Bay so I am not presently sure when I can spend some time with you in Waltham talking about your report. I will call when my plans settle down.

Sincerely,

Charlie McClennen

Charles E. McClennen
Associate Professor

hdp

DISPOSITION FORM

For use of this form, see AR 340-15, the proponent agency is TAGCEN.

REFERENCE OR OFFICE SYMBOL	SUBJECT
NEDPL-C	Cape Cod Easterly Shores Beach Erosion Control Study

TO Division Engineer FROM Project Manager DATE 28 Sept 78 CMT 1
THRU: Channels Mr. Bruha/mc/554

1. On 29-30 August 1978 the undersigned visited the subject study area with a representative of the U.S. Soil Conservation Service and National Park Service officials to discuss the final recommendations of the subject report. Because the report will limit its recommendations to non-structural erosion control methods and the report is complete in draft form, a coordination meeting and trip was necessary before finalizing the report and returning it to the A/E for final typing.

2. Mr. Richard Devergilio of the U.S. Soil Conservation Service and I visited beach areas belonging to both the National Park Service and the towns. We discussed sand fences and various types of plantings that could be effective in this type of area under various wind, wave and storm conditions. Mr. Devergilio agreed to submit to us a brief report suggesting alternative types of vegetation that could be used in different areas depending upon its exposure to salt water spray, wind, traffic, etc.

3. The various suggestions and alternative methods of non-structural improvements to be recommended in the report were discussed at length with Mr. James Killian, Chief of Maintenance for the park service. Grass planting, sandfencing and a program of educational films and workshops using the visitors center and other park service facilities was well received by Mr. Killian. He saw no objection to these non-structural suggestions and stated that these methods reinforce their position with the towns located within the National Park Service boundaries. He also mentioned that the park service has been trying for sometime to encourage the towns to control the access to their beaches, develop a program of dune restoration and encourage protection and stabilization of the backshore dunes.

4. Mr. Killian and I also discussed the breach in the Wood End Bar that separates Cape Cod Bay from House Point Island flats and the Corps dike constructed across the flats (see attached map). A section of Wood End Bar was opened during the 6 February 1978 storm. The opening varies from about 200 feet at low tide, mean low water to about 600 feet at high tide, mean high water. The park service has taken a do nothing approach to this problem because they feel that the opening will eventually close naturally. My concern is that if the opening is allowed to remain open and does not close naturally, will it impact our dike? We are now approaching the winter storm season and I feel that the dike should be looked at by our engineers to evaluate the potential impact on the structure. If the breach does not close naturally and storm driven waves cause erosion of the dunes, will the southern end of the dike flank, causing damage to the structure and the deposition of material in Provincetown Harbor? Hopefully the opening will close naturally but if it does not, an evaluation of the possible impact on the structure and the area should be made and documented. This matter has been discussed with Operations and Engineering divisions.

Inclosure:
as

cc: Coastal Dev. Branch
Planning Div. File
Engineering Div.
Operations Div.

BRUHA

Appendix 4
G-27

DA FORM 2496 REPLACES DD FORM 96, WHICH IS OBSOLETE.

GPO 1976 665 422 1063

Town of Eastham

NATURAL RESOURCES DEPARTMENT
P.O. BOX 302

EASTHAM
MASSACHUSETTS
02642

4 October 1978

Mr. Thomas Bruha
Corps of Engineers
424 Trapelo Road
Waltham Ma 02154

Dear Mr. Bruha:

This letter will serve to confirm our recent telephone converstaion concerning the shellfish populations in Nauset Marsh in the Town of Eastham.

Presently, large populations of soft shell clams (Mya arenaria) may be found in many areas in themarsh. These populations consist of two separate year classes; those which set during summer, 1977, and a second seed population which set during the summer of 1978. The 1977 year class is largely made up of clams of at least two inches in length, which is the legal minimum size for harvest. About ten commercial shellfishermen are actively engaged in digging in these areas, with yields as high as ten bushels per man per day. Should these areas be covered with overwash sand they would in all probability be totally lost.

It is difficult to estimate the quantity of shellfish available for digging along the inside of the barrier beach, but it could be safely assumed to be on the order of thousands of bushels.

The hydrographic conditions in Nauset Marsh with the Inlet in its present location are such that certain areas achieve high water temperatures and low flushing rates. Such conditions are ideal for the rapid setting and growth of juvenile shellfish. One such area is Salt Pond, where the Town operates a hatchery and nursery program for recruitment of shellfish stock. If hydrographic conditions were to change significantly so as to alter this tidal flow and temperature regime, the program would suffer losses.

Although I am not qualified as a coastal engineer my observations of the processes of overwash ing on Nauset Beach

Mr. Thomas Bruha
4 October 1978
page 2

lead to the conclusion that some type of passive sand stabilization may be effective in reducing the amount of sand transported into the marsh. A program of grass planting coupled with artificial nourishment of the beach would be worth investigating as a means to protect our shellfish resources.

If I may be of further assistance in this matter, please do not hesitate to contact me.

Sincerely,

Henry Lind
Natural Resources Officer

SECTION H

REPORT REVIEW AND OTHER CONTRIBUTIONS

SECTION H

REPORT REVIEW AND OTHER CONTRIBUTIONS

TABLE OF CONTENTS

INTRODUCTION

The New England Division of the Corps of Engineers is appreciative of the cooperation and technical assistance rendered by other federal and state agencies and private engineering firms, and the local communities for their input, cooperation and support in developing and assisting their office in the completion of this report.

During the preparation of the report, we have tried to include pertinent data either from reliable known published sources or we have developed or have had information developed for us by reliable persons knowledgeable in the field of coastal processes and the problems and needs pertinent to Cape Cod.

It is the intention of the New England Division to credit individuals and organizations that have contributed to this report. If for any reason anyone has inadvertently been omitted from the below list, please notify the New England Division, Corps of Engineers, Waltham, Massachusetts 02154.

NAMES	ORGANIZATIONS
Dr. Lee Harris	Corps of Engineers CERC
Dr. Frank Fesenden	Corps of Engineers and Bentley College
Dr. Graham Giese	Provincetown Center for Coastal Studies
Dr. Steven P. Leatherman	National Park Service and University of Massachusetts Amherst
Dr. John J. Fisher	University of Rhode Island
Mr. Joseph L. Ignazio	Corps of Engineers
Mr. Donald W. Martin	Corps of Engineers
Mr. Oscar Arpin	Consulting Engineer
Mr. Edward Blackey	Corps of Engineers
Mr. Richard Debuono	Corps of Engineers
Mr. Steven Rubin	Corps of Engineers
Mr. Jack Sargent	Corps of Engineers
Mr. James McDevitt	Corps of Engineers
Mr. Cecil Wentworth	Consulting Engineer
Mr. Steven Onysko	Corps of Engineers
Mrs. Jill Pontius	Corps of Engineers
Mrs. Barbara Carlson	Corps of Engineers
Ms. Maureen Cummings	Corps of Engineers

NAMES	ORGANIZATIONS
Mr. Larry Gatto	Corp--CRREL
Mrs. Leah Smith	Consulting Engineer EG&G International Inc.
Dr. Malcolm Spaulding	University of Rhode Island
Dr. Pter Cornillon	University of Rhode Island
Mr. Arnold R. C. Lane	Cooperative Extension Service
Mr. Philip Christenson	U.S. Soil Conservation Service
Mr. Richard Devergilio	U.S. Soil Conservation Service
Mr. Charles E. McClennen	Colgate University
Mr. Henry Lind	Town of Eastham Natural Resources Office
Mr. David Chadwick	Massachusetts Division of Marine Fisheries
Ms. Theresa Schwartz	United States Fish and Wildlife Service
Mr. Carl Schwartz	United States Fish and Wildlife Service
Mr. Gordon E. Beckett	United States Fish and Wildlife Service
Mrs. Martha Murphy	Analysis & Technology, Inc. Consulting Engineers
Mrs. Anne Nalwalk	Analysis & Technology, Inc.
Mr. Gerard Robinson	Analysis & Technology, Inc.
Mr. John J. Hannon	Commonwealth of Massachusetts Office of Environmental Quality Engineering
Mr. Lawrence C. Hadley	National Park Service
Mr. James Killian	National Park Service
Mr. Lester Smith	CZM, Massachusetts Executive Office of Environmental Affairs

APPENDIX 5

GLOSSARY

PREPARED BY THE NEW ENGLAND DIVISION

CORPS OF ENGINEERS

DEPARTMENT OF THE ARMY

GLOSSARY OF TERMS

ACCRETION - A buildup of land which may be either natural or artificial. Natural accretion is the buildup of land, solely by the forces of nature, on a BEACH by deposition of waterborne or airborne material. Artificial accretion is a similar buildup of land by an act of man, such as the accretion formed by a groin, breakwater, or beach fill deposited by mechanical means.

ADVANCE (OF A BEACH) - (1) A continuing seaward movement of the shoreline. (2) A net seaward movement of the shoreline over a specified time.

ALONGSHORE - Parallel to and near the shoreline; same as LONGSHORE.

AMPLITUDE, WAVE - The magnitude of the displacement of a wave from a mean value. An ocean wave has an amplitude equal to the vertical distance from stillwater level to wave crest. For a sinusoidal wave, amplitude is one-half the wave height.

AQUIFER - Stratum or zone below the surface of the earth capable of producing water.

ARTIFICIAL NOURISHMENT - The process of replenishing a beach with material (usually sand) obtained from another location.

AWASH - Situated so that the top is intermittently washed by waves or tidal action. Condition of being exposed or just bare at any stage of the tide between high water and chart datum.

B.P. - Before present.

BACKSHORE - The zone of a shore or beach lying between the foreshore and the coastline and acted upon by waves only during severe storms, especially when combined with exceptionally high water. It comprises the BERM or BERMS. (See Figure 1 located at the end of glossary.)

BACKWASH - (1) The seaward return of the water following the uprush of the waves. (2) Water or waves thrown back by an obstruction such as a ship, breakwater or cliff.

BANK - (1) The rising ground bordering a lake, river or sea; the face of a scarp. (2) An elevation of the sea floor of large area, located on a continental (or island) shelf and over which the depth is relatively shallow but sufficient for safe surface navigation; a group of shoals. (3) In its secondary sense, a shallow area consisting of shifting forms of silt, sand, mud and gravel, but in this case it is only used with a qualifying word such as "sandbank" or "gravelbank".

BAR - A submerged or emerged embankment of sand, gravel or other unconsolidated material built on the sea floor in shallow water by waves and currents, especially at the mouth of a river or estuary or lying a short distance from, and usually parallel to, the beach. See BAYMOUTH BAR.

BARRIER BEACH - A bar essentially parallel to the shore, the crest of which is above normal high water level.

BASEMENT - Rock complex, generally of IGNEOUS and METAMORPHIC rocks, overlain UNCONFORMABLY by SEDIMENTARY strata.

BATHYMETRY - The measurement of depths of water in oceans, seas and lakes; also information derived from such measurements.

BAY - A recess in the shore or an inlet of a sea between two capes or headlands, not as large as a gulf but larger than a cove.

BAYMOUTH BAR - A bar extending partly or entirely across the mouth of a bay.

BEACH - A zone of unconsolidated material that extends landward from the low-water line to the place where there is marked change in material or physiographic form, or to the line of permanent vegetation (usually the effective limit of storm waves). The seaward limit of a beach - unless otherwise specified - is the mean low-water line. A beach includes FORESHORE and BACKSHORE. (See Figure 1.)

BEACH ACCRETION - See ACCRETION.

BEACH BERM - A flat terrace located at the top of the foreshore. Also, a nearly horizontal part of the beach or backshore formed by the deposit of material by wave action. Some beaches have no berms, others have one or several. (See Figure 1.)

BEACH EROSION - The carrying away of beach materials by wave action, tidal currents, littoral currents or wind.

BEACH WIDTH - The horizontal dimension of the beach measured perpendicular to the shoreline.

BED - The smallest division of a stratified series, marked by a more or less well-defined divisional plane from its neighbors above and below.

BED FORMS - Any deviation from a flat bed that is readily detectable by eye, and higher than the largest sediment size present in the parent bed material; generated on the bed of an alluvial channel by the flow.

BEDROCK - Any solid rock exposed at the surface of the earth or overlaid with unconsolidated material.

BERM, BEACH - See BEACH BERM.

BERM CREST - The seaward limit of a berm. (See Figure 1.)

BLOWOUT - A general term for various saucer-, cup- or trough-shaped hollows formed by wind erosion on a preexisting dune or other sand deposit.

BLUFF - Any high headland or bank presenting a precipitous front.

BOTTOM - The ground or bed under any body of water; the bottom of the sea. (See Figure 1.)

BOULDER - A rounded rock more than 10 inches in diameter.

BREAKER - A wave breaking on a shore.

BREAKER-SHORELINE ANGLE - See SHORELINE-BREAKER ANGLE.

BREAKWATER - A structure protecting a shore area, harbor, anchorage or basin from waves.

CHANNEL - (1) The part of a body of water deep enough to be used for navigation through an area otherwise too shallow for navigation. (2) The deepest part of a stream, bay or strait though which the main volume or current of water flows.

CHART DATUM - The plane or level to which soundings (or elevations) or tide heights are referenced. The surface is called a tidal datum when referred to a certain phase of tide. See DATUM PLANE.

CLASTIC - Consisting of fragments of rocks or of organic structures that have been moved individually from their place of origin.

CLAY - Fine-grained soil consisting of organic material the grains of which have diameters smaller than 0.005 millimeters. Finer than SILT.

CLIFF - A high, steep face of rock; a precipice. See also MARINE CLIFF and SEA CLIFF.

COAST - A strip of land of indefinite width (may be several miles) that extends from the shoreline inland to the first major change in terrain features. (See Figure 1.)

COASTAL AREA - The land and sea area bordering the shoreline. (See Figure 1.)

COASTAL PLAIN - A plain composed of horizontal or gently sloping strata of CLASTIC materials fronting the coast.

COASTLINE - (1) Technically, the line that forms the boundary between the COAST and the SHORE. (2) Commonly, the line that forms the boundary between the land and the water.

COBBLE - A rock fragment between 65 and 256 millimeters in diameter, thus larger than a PEBBLE and smaller than a BOULDER, rounded or otherwise abraded in the course of aqueous, eolian or glacial transport.

CONTINENTAL SHELF - The zone bordering a continent and extending from the low-water line to the depth (usually about 100 fathoms) where there is a marked or rather steep descent toward a greater depth.

CONTOUR - A line on a map or chart representing points of equal elevation with relation to a datum.

CONVERGENCE - (1) In refraction phenomena, the decreasing of the distance between ORTHOGONALS in the direction of wave travel. Denotes an area of increasing wave height and energy concentration. Also FOCUSING. (2) In wind-setup phenomena, the increase in setup observed over that which would occur in an equivalent rectangular basin of uniform depth, caused by changes in planform or depth; also the decrease in basin width or depth causing such increase in setup.

COVE - A small, sheltered recess in a coast, often inside a larger embayment.

CREEP - Movement of an individual sand grain as a result of being hit by a windborne sand grain.

CREST OF WAVE - (1) The highest part of a wave. (2) That part of the wave above stillwater level. (See Figure 2 located at the end of the glossary.)

CROSSBEDDING - The arrangement of laminations of strata transverse or oblique to the main planes of stratification of the strata concerned; inclined, often lens-shaped beds between the main bedding planes.

CRYSTALLINE - An inexact general term for igneous or metamorphic rocks as opposed to sedimentary rocks.

CULM - STEM of grasses, usually hollow except at the swollen NODES.

CULTURAL EROSION - Erosion caused by effects of man's actions on the land - excavation, traffic (vehicular and foot) and construction (inland and shoreline).

CURRENT - A flow of water due to surface gradient, tidal phenomena, winds and/or differential atmospheric pressures.

CURRENT, EBB - The tidal current away from shore. Usually associated with the decrease in the height of the tide.

CURRENT, FLOOD - The tidal current toward shore. Usually associated with the increase in the height of the tide.

CURRENT, LITTORAL - Any current in the littoral zone caused primarily by wave action, e.g., longshore current, rip current.

CURRENT, LONGSHORE - The littoral current in the breaker zone moving essentially parallel to the shore, usually generated by waves breaking at an angle to the shoreline.

CURRENT RIPPLE - A ripple mark produced by the action of a current flowing steadily in one direction over a bed of sand. See RIPPLES (BED FORMS).

CURRENT, TIDAL - The alternating horizontal movement of water associated with the rise and fall of the tide caused by the astronomical tide-producing forces. See also CURRENT, FLOOD and CURRENT, EBB.

CYCLONE - In the northern hemisphere, a storm characterized by strong winds rotating counterclockwise about a center of low atmospheric pressure.

DATUM, CHART - See CHART DATUM.

DATUM PLANE - The horizontal plane to which soundings, ground elevations or water surface elevations are referred. Also REFERENCE PLANE. The plane is called a TIDAL DATUM when defined by a certain phase of the tide. On the Atlantic coast of the United States MEAN LOW WATER is the datum ordinarily used on hydrographic charts. A common datum used on topographic maps is based on MEAN SEA LEVEL.

DEEP WATER - Water so deep that surface waves are little affected by the ocean bottom. Generally, water deeper than one-half the surface wavelength is considered deep water.

DEFLATION - The removal of loose material from a beach or other land surface by wind action.

DEFOCUSING - See DIVERGENCE. The spreading farther apart of wave rays in shallow water than in deep water; height or amplitude of the breaking wave is less than at points where no defocusing occurs.

DEGLACIATION - The uncovering of an area from beneath glacier ice as a result of shrinkage of a glacier.

DELTA - An alluvial deposit, roughly triangular or digitate in shape, formed at a river mouth.

DENUDATION - The stripping of forests and vegetation from the land.

DEPTH - The vertical distance from a specified tidal datum to the sea floor.

DEPTH CONTOUR - See CONTOUR.

DISCOID - Having the form of a disk.

DIVERGENCE - (1) In refraction phenomena, the increasing of distance between ORTHOGONALS in the direction of wave travel. Denotes an area of decreasing wave height and energy concentration. Also DEFOCUSING. (2) In WIND-SETUP phenomena, the decrease in setup observed under that whiche would occur in an equivalent rectangular basin of uniform depth, caused by changes in planform or depth. Also the increase in basin width or depth causing such decrease in setup.

DOWNDRIFT - The direction of predominant movement of littoral materials.

DRIFT (noun) - (1) Sometimes used as a short form for LITTORAL DRIFT. (2) The speed at which a current runs. (3) Also floating material deposited on a beach (driftwood). (4) A deposit of a continental ice sheet, as a drumlin.

DRIFT DEPOSIT - Any accumulation of glacial origin; glacial or glaciofluvial deposit.

DUNE - Ridge or mound of loose, windblown material, usually sand.

EBB CURRENT - The tidal current away from shore or down a tidal stream; usually associated with the decrease in the height of the tide.

EBB TIDE - The period of tide between high water and the succeeding low water; a falling tide.

EMBAYMENT - An indentation in the shoreline forming an open bay.

EOLIAN SANDS - Sediments of sand size or smaller which have been transported by winds. They may be recognized in marine deposits off desert coast by the greater angularity of the grains compared with waterborne particles.

EQUATORIAL TIDES - Consecutive tides with similar ranges occurring when the moon's orbit is on or close to the equator; morning and afternoon tides are very much alike.

EROSION - The wearing away of land by the action of natural forces. On a beach, the carrying away of beach material by wave action, tidal currents, littoral currents, or by deflation.

EYE - In meteorology, usually the "eye of the storm" (hurricane); the roughly circular area of comparatively light winds and fair weather found at the center of a severe tropical cyclone.

EUSTATIC - Pertaining to simultaneous, world-wide changes in sea level; also related to the amount of water incorporated in ice caps.

EUTROPHICATION - Process occurring in a lake making it rich in dissolved nutrients, but deficient in oxygen.

FAN - An accumulation of debris brought down by a stream descending a steep ravine and debouching in the plain beneath, where the detrital material spreads out in the shape of a fan.

FATHOM - A unit of measurement used for soundings. It is equal to 6 feet (1.83 meters).

FETCH - The continuous area of open water over which the wind blows in a constant direction. In enclosed bodies of water, it would usually coincide with the longest axis in the general wind direction. Sometimes used synonymously with FETCH LENGTH.

FETCH LENGTH - The horizontal distance (in the direction of the wind) over which the wind blows to generate SEAS or create a WIND SETUP.

FLOOD CURRENT - The tidal current toward shore, usually associated with the increase in the height of the tide.

FLOOD PLAIN - That portion of a river valley, adjacent to the river channel, that is built of sediments during the present regimen of the stream and that is covered with water when the river overflows its banks at flood stages.

FLOOD TIDE - The period of tide between low water and the succeeding high water; a rising tide.

FLUVIAL - Of or pertaining to rivers; produced by river action, as a fluvial plain.

FOCUSING - See CONVERGENCE. The closing together of wave rays in shallow water; height of breaking wave is greater than at points where there is no focusing.

FOREDUNE - The front dune immediately behind the backshore.

FORESHORE - The part of the shore lying between the crest of the seaward berm (or upper limit of wave wash at high tide) and the ordinary low-water mark that is ordinarily traversed by the uprush and backrush of the waves as the tides rise and fall. (See Figure 1.)

FOSSIL - The remains or traces of animals or plants that have been preserved by natural causes in the earth's crust exclusive of organisms that have been buried since the beginning of historic time.

FOSSILIFEROUS - Containing organic remains.

FRONTAL MARGIN - The leading edge of a glacier.

FULCRUM POINT - Point at which there is no net erosion or accretion; erosion occurs on one side of the fulcrum point, accretion on the other.

GALE - Continuous winds with velocities in excess of 32 miles per hour.

GENERATION OF WAVES - (1) The creation of waves by natural or mechanical means. (2) The creation and growth of waves caused by a wind blowing over a water surface for a certain period of time.

GLACIAL - Pertaining to, characteristic of, produced or deposited by or derived from a glacier.

GLACIAL DRIFT - Sediment (a) in transport in glaciers, (b) deposited by glaciers, and (c) predominantly of glacial origin, made in the sea or in bodies of glacial meltwater. See DRIFT.

GLACIATION - Alteration of the earth's solid surface through erosion and deposition by glacier ice.

GLACIER - A mass of ice with definite lateral limits, with motion in a definite direction and originating from the compacting of snow by pressure.

GLACIO- - A combining form frequently used with other words to denote formation by or relationship to glaciers.

GLACIOFLUVIAL - Pertaining to streams flowing from glaciers or to the deposits made by such streams.

GLACIOLACUSTRINE - Produced by or belonging to glacial lakes.

GRADIENT (GRADE) - With reference to winds or currents, the rate of increase or decrease in speed, usually in the vertical; or the curve that represents this rate. The change in a variable quantity, as temperature, per unit distance.

GRANITE - Loosely used for any light-colored, coarse-grained igneous rock. Actually an igneous rock consisting of essentially alkalic feldspar and quartz.

GRANITIC - Pertaining to or composed of granite or granite-like rock.

GRAVEL - Accumulation of rounded, waterworn PEBBLES. The word gravel is generally applied when the size of the pebbles does not much exceed that of an ordinary hen's egg; fragment size ranges from 76 to 4.76 millimeters; may or may not contain interstitial sand ranging from 50 to 70 percent of the total mass.

GROIN - A shore protection structure built (usually perpendicular to the shoreline) to trap littoral drift or retard erosion of the shore.

GROIN SYSTEM - A series of groins acting together to protect a section of beach. Commonly called a groin field.

GROUNDWATER - Subsurface water occupying the zone of saturation. In a strict sense, the term is applied only to water below the WATER TABLE.

GULF - A large embayment in a coast; the entrance is generally wider than the length.

HANGING VALLEY - A tributary valley whose floor is higher than the floor in the area of intersection.

HARBOR - Any protected water area affording a place of safety for vessels.

HEADLAND (HEAD) - A high, steep-faced promontory extending into the sea.

HEIGHT OF WAVE - See WAVE HEIGHT.

HIGH TIDE, HIGH WATER (HW) - The maximum elevation reached by each rising tide. See TIDE.

HIGH WATER - See HIGH TIDE.

HIGH-WATER MARK - In the strict sense, the intersection of the plane of mean high water with the shore. The shoreline delineated on the nautical charts of the U.S. Coast and Geodetic Survey is an approximation of the high-water line. For specific occurrences, the highest elevation on the shore reached during a storm or rising tide, including meteorological effects.

HOLLOW - A small ravine; a low tract of land encompassed by hills.

HOOK - A spit or narrow cape of sand or gravel which turns landward at the outer end.

HURRICANE - An intense tropical cyclone in which winds tend to spiral inward toward a core of low pressure, with maximum surface wind velocities that equal or exceed 75 miles per hour (65 knots) for several minutes or longer at some points. TROPICAL STORM is the term applied if maximum winds are less than 75 miles per hour.

HURRICANE PATH OR TRACK - Line of movement (propagation) of the eye through an area.

HYDROLOGY - The science that relates to the water of the earth.

IGNEOUS - Formed by solidification from a molten or partially molten state.

INLET - (1) A short, narrow waterway connecting a bay, lagoon or similar body of water with a large parent body of water. (2) An arm of the sea (or other body of water) that is long compared to its width and that may extend a considerable distance inland.

IN-MIGRATION - The net increase in population due to an excess of people moving in over people moving out.

INSHORE (ZONE) - The zone of variable width extending from the low-water line through the breaker zone. (See Figure 1.)

JETTY - On open seacoasts, a structure extending into a body of water and designed to prevent shoaling of a channel by littoral materials and to direct and confine the stream or tidal flow. Jetties are built at the mouth of a river or tidal inlet to help deepen and stabilize a channel.

KAME - A conical hill or short irregular ridge of gravel or sand deposited in contact with glacial ice.

KETTLE - A pit or depression in drift made by the wasting away of a detached mass of glacier ice that had been either wholly or partly buried in the drift.

KINETIC ENERGY (OF WAVES) - In a progressive oscillatory wave, a summation of the energy of motion of the particles within the wave.

KNOT - The unit of speed used in navigation. It is equal to 1 nautical mile (6,076.115 feet or 1,852 meters) per hour; about 1.15 statute miles per hour.

LAGOON - A shallow body of water, as a pond or lake, usually connected to the sea.

LANDFILL - A system of trash and garbage disposal in which the waste is buried between layers of earth.

LEACHATE - Highly concentrated effluent resulting from the leaching of landfills.

LEE - Shelter, or the part sheltered (or turned away) from the wind or waves.

LENGTH OF WAVE - The horizontal distance between similar points on two successive waves measured perpendicularly to the crest (See Figure 2.)

LIFT - A section of sand or snow fence designed to catch and hold windblown sand to increase the height of a dune.

LITHOLOGY - The physical character of a rock, generally determined megascopically or with the aid of a low-power magnifier.

LITTORAL - Of or pertaining to a shore, especially of the sea.

LITTORAL CURRENT - See CURRENT, LITTORAL.

LITTORAL DEPOSITS - Deposits of littoral drift.

LITTORAL DRIFT - The sedimentary material moved in the littoral zone under the influence of waves and currents.

LITTORAL TRANSPORT - The movement of littoral drift in the littoral zone by waves and currents. Includes movement parallel (longshore transport) and perpendicular (onshore and offshore transport) to the shore.

LITTORAL TRANSPORT RATE - Rate of transport of sedimentary material parallel or perpendicular to the shore in the littoral zone. Usually expressed in cubic yards (meters) per year. Commonly used as synonymous with LONGSHORE TRANSPORT RATE.

LITTORAL ZONE - An indefinite zone extending seaward from the shoreline to just beyond the breaker zone.

LOBE - A projection of a glacial margin or of a body of glacial drift beyond the main mass of ice or drift.

LONGSHORE - Parallel to and near the shoreline.

LONGSHORE CURRENT - See CURRENT, LONGSHORE.

LONGSHORE ENERGY FLUK - It is equal to the component of wave energy flux per unit length of shoreline which is parallel to the shoreline. (See WAVE ENERGY FLUX.)

LONGSHORE TRANSPORT - The movement of sedimentary material parallel to the shore. The rate of longshore transport is usually expressed in cubic yards (meters) per year. Commonly used as synonymous with LITTORAL TRANSPORT.

LOW PASS FILTER - A device (electronic or digital) that attenuates the higher frequency components of a signal but that leaves the amplitude of the lower frequency components unaffected.

LOW TIDE (LOW WATER, LW) - The minimum elevation reached by each falling tide. See TIDE.

LOW-WATER MARK - The intersection of any standard low tide datum plane with the shore.

MARINE CLIFF - A cliff, sometimes composed of unconsolidated sediments, facing the ocean and formed by wave action.

MARSH - An area of soft, wet or periodically inundated land, generally treeless and usually characterized by grasses and other low growth.

MARSH, SALT - A marsh periodically flooded by salt water.

MASS TRANSPORT - The net transfer of water by wave action in the direction of wave travel. See ORBIT.

MEAN HIGH WATER (MHW) - The average height of the high waters over a 19-year period. For shorter periods of observations, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value.

MEAN LOW WATER (MLW) - The average height of the low waters over a 19-year period. For shorter periods of observations, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value.

MEAN SEA LEVEL - The average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings.

MELT WATER - Water resulting from the melting of snow or of glacial ice.

METAMORPHIC ROCK - Includes all those rocks that have formed in the solid state in response to pronounced changes of temperature, pressure and chemical environment, which generally take place below the zones of weathering and cementation.

MIGRATE - To translocate (as a dune, spit or inlet, more or less as a unit) under the continued action of wind, waves and currents.

MORAINE - Drift deposited chiefly by direct glacial action and having constructional topography independent of control by the surface on which the drift lies.

MORPHOLOGY - The observation of the form of lands.

MUD - A fluid-to-plastic mixture of finely divided particles of solid material and water.

MUD FLAT - An accumulation of mud that is exposed at low tide and covered by shallow water at high tide.

NAUTICAL MILE - Generally 1 minute of latitude is considered equal to 1 nautical mile. The accepted United States value as of 1 July 1959 is 6,076.115 feet or 1,852 meters, approximately 1.15 times as long as the statute mile of 5,280 feet. Also geographical mile.

NEAP TIDE - A tide occurring near the time of quadrature of the moon with the sun. The neap tidal range is usually 10 to 30 percent less than the mean tidal range.

NEARSHORE (ZONE) - An indefinite zone extending seaward from the shoreline well beyond the breaker zone. (See Figure 1.)

NODAL POINT - The point where the predominant direction of the LONGSHORE TRANSPORT changes. The point at which the longshore current or sediment transport changes sign.

NODE - Joint of a STEM where a leaf is borne or may be borne. Buds are also commonly borne at the node.

NORTHEASTER - Any east coast storm (except a hurricane) of the middle Atlantic and New England states that produces strong onshore winds.

NOURISHMENT - The process of replenishing a beach. It may be brought about naturally by longshore transport or artificially by the deposition of dredged materials.

NUTRIENT - A nutritive substance or ingredient, referring here to organic nutrients in the soil and underlying sediments both above and in the water table.

OFFSHORE - (1) The comparatively flat zone of variable width, extending from the breaker zone to the seaward edge of the Continental Shelf. (2) A direction seaward from the shore. (See Figure 1.)

OFFSHORE WIND - A wind blowing from land to sea in the coastal area.

ONSHORE - A direction from sea to land.

ONSHORE WIND - A wind blowing from sea to land in the coastal area.

ORBIT - In water waves, the path of a water particle affected by the wave motion. In deep-water waves the orbit is nearly circular and in shallow-water waves the orbit is nearly elliptical. In general, the orbits are slightly open in the direction of wave motion giving rise to MASS TRANSPORT.

ORTHOGONALS - On a wave-refraction diagram, a line drawn perpendicular to the wave crests. Also WAVE RAY.

OUTFALL - A structure extending into a body of water for the purpose of discharging sewage, storm runoff or cooling water.

OUTWASH - Materials deposited by meltwater streams beyond active glacier ice.

OUTWASH PLAIN - Fan-shaped overlapping deltas deposited by streams flowing from the glacier.

OVERTOPPING - Passing of water over the top of a structure as a result of wave runup or surge action.

PAMET - An outwash channel carved in glacial drift and having irregularities resulting from melting of blocks of stagnant ice.

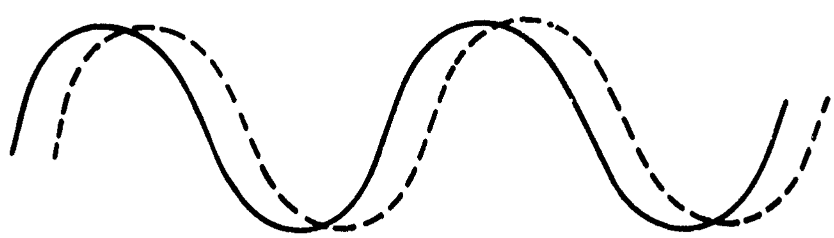
PAMET SAG - Depression in the edge of the scarp caused by its intersection by a pamet.

PARABOLIC DUNE - A dune having (in ground plan) approximately the form of a parabola, with the concave side toward the wind.

PEAT - A dark-brown or black residuum produced by the partial decomposition of various plants (mosses, trees, etc.) that grow in marshes and similar wet places.

PEBBLES - Smooth rounded stones ranging in diameter from 2 to 64 millimeters.

PHASE SHIFT - A shift to the right or left of a sine wave.



PHI GRADE SCALE - A logarithmic transformation of the Wentworth grade scale for size classification of sediment grains based on the negative logarithm to the base 2 of the particle diameter. Measured in Phi units.

PITTED OUTWASH PLAIN - An outwash plain of gravel or sand with kettle holes.

PLAIN, COASTAL - See COASTAL PLAIN.

PLEISTOCENE - The earlier of the two epochs comprising the Quaternary period. Also called Glacial epoch and formerly called Ice Age.

POINT - The extreme end of a cape or the outer end of any land area protruding into the water, usually less prominent than a cape.

PROFILE, BEACH - The intersection of the ground surface with a vertical plane; may extend from the top of the dune line to the seaward limit of sand movement. (See Figure 1.)

PROGLACIAL LAKE - Lake occupying a basin in front of a glacier generally in direct contact with the ice.

PROGRADATION - A seaward advance of the beach berm.

PROPAGATION OF WAVES - The transmission of waves through water.

QUARTZITE - A granulose metamorphic rock consisting essentially of quartz.

RADIOCARBON DATING - The determination of the age of a material by measuring the propagation of the isotope C^{14} (radiocarbon) in the carbon it contains. The method is suitable for the determination of ages up to a maximum of about 30,000 years.

RECESSION (of a beach) - (1) A continuing landward movement of the shoreline. (2) A net landward movement of the shoreline over a specified time. Also RETROGRESSION.

RECESSIONAL MORAINE - A moraine formed during a temporary decrease in the rate of glacial retreat.

RECHARGE - The processes by which water is absorbed and is added to the zone of saturation. Also, the quantity of water that is added to the zone of saturation.

RECURVED SPIT - A SPIT having one end more or less strongly curved inward (landward).

REFRACTION (OF WATER WAVES) - (1) The process by which the direction of a wave, moving in shallow water at an angle to the contours, is changed. The part of the wave advancing in shallower water moves more slowly than that part still advancing in deeper water, causing the wave crest to bend toward alignment with the underwater contours. (2) The bending of wave crests by currents.

RETROGRADATION - The cutting back of a beach toward land.

RETROGRESSION OF A BEACH - (1) A continuing landward movement of the shoreline. (2) A net landward movement of the shoreline over a specified time. Also RECESSION, RETROGRADATION.

REVETMENT - A facing of stone, concrete, etc., built to protect a scarp, embankment or shore structures against erosion by wave action or currents.

RIP CURRENT - A strong surface current flowing seaward from the shore. It usually appears as a visible band of agitated water and is the return movement of water piled up on the shore by incoming waves and wind. With the seaward movement concentrated in a limited band, its velocity is somewhat accentuated.

RIPPLES (BED FORMS) - Small bed forms with wavelengths less than 1 foot and heights less than 0.1 foot.

RIPRAP - A layer, facing or protective mound of stones randomly placed to prevent erosion, scour or sloughing of a structure or embankment; also the stone so used.

RUBBLE - (1) Loose angular waterworn stones along a beach. (2) Rough, irregular fragments of broken rock.

RUBBLE-MOUND STRUCTURE - A mound of randomly shaped and randomly placed stones protected with a cover layer of selected stones or specially shaped concrete armor units. (Armor units in primary cover layer may be placed in orderly manner or dumped at random.)

SALTATION - That method of sand movement in a fluid in which individual particles leave the bed by bounding nearly vertically and, because the motion of the fluid is not strong or turbulent enough to retain them in suspension, return to the bed at some distance downstream. The travel path of the particles is a series of hops and bounds.

SALT MARSH - A mud flat that has reached sea level enabling salt-tolerant plants to grow, thus producing a tough, erosion-resistant vegetal mat that reaches approximately the level of high tide.

SAND - Detrital material ranging in size from 2 to 1/16 millimeters in diameter.

SANDBAR - See BAR.

SANDFILL - Sand added to a beach as a shore-protection measure.

SCARP - A more or less continuous line of cliffs or steep slopes facing in one general direction that are caused by erosion or faulting. (See Figure 1.)

SCARP, BEACH - An almost vertical slope along the beach caused by erosion by wave action. It may vary in height from a few inches to several feet, depending on wave action and the nature and composition of the beach. (See Figure 1.)

SCOUR - Removal of underwater material by waves and currents, especially at the base or toe of a shore structure.

SEA CLIFF - A cliff situated at the seaward edge of the coast and formed by wave action.

SEA LEVEL - See MEAN SEA LEVEL.

SEAS - Waves caused by wind at the place and time of observation.

SEAWALL - A structure separating land and water areas, primarily designed to prevent erosion and other damage due to wave action.

SEDIMENT - Solid material, both mineral and organic, that is in suspension, is being transported or has been moved from its site of origin by air, water or ice and has come to rest on the earth's surface either above or below sea level.

SEDIMENTARY ROCKS - Rocks formed by the accumulation of sediment in water (aqueous deposits) or from air (eolian deposits). The fragments or particles are of various sizes (conglomerate, sandstone, shale), of the remains or products of animals or plants (certain limestones and coal), of the product of chemical action or of evaporation (salt, gypsum, etc) or of mixtures of these materials. A characteristic feature of sedimentary deposits is a layered structure known as bedding or stratification. Each layer is a bed or stratum. Sedimentary beds as deposited lie flat or nearly flat.

SEPTAGE - The solid waste from on-site septic systems.

SETUP, WAVE - Superelevation of the water surface over normal surge elevation due to onshore mass transport of the water by wave action alone.

SETUP, WIND - See WIND SETUP.

SHALLOW WATER - (1) Commonly, water of such a depth that surface waves are noticeably affected by bottom topography. It is customary to consider water of depths less than one-half the surface wavelengths as shallow water. See DEEP WATER. (2) More strictly, in hydrodynamics with regard to progressive gravity waves, water in which the depth is less than 1/25 the wave-length. Also called very shallow water.

SHINGLE - (1) Loosely and commonly, any beach material coarser than ordinary gravel, especially any having flat or flattish pebbles. (2) Strictly and accurately, beach material of smooth, well-rounded pebbles that are roughly the same size. The spaces between pebbles are not filled with finer materials. Shingle often gives out a musical sound when stepped on.

SHOAL (noun) - A detached elevation of the sea bottom, comprised of any material except rock or coral, which may endanger surface navigation.

SHOAL (verb) - (1) To become shallow gradually. (2) To cause to become shallow. (3) To proceed from a greater to a lesser depth of water.

SHORE - The narrow strip of land in immediate contact with the sea, including the zone between high and low water lines. A shore of unconsolidated material is usually called a beach. (See Figure 1.)

SHORELINE - The intersection of a specified plane of water with the shore or beach (e.g., the high-water shoreline would be the intersection of the plane of mean high water with the shore or beach.) The line delineating the shoreline on U. S. Coast and Geodetic Survey nautical charts and surveys approximates the mean high-water line.

SHORELINE-BREAKER ANGLE - The angle that a breaking wave makes with the shoreline.

SILICIFIED - Replaced by or having the interstitial spaces filled with fine-grained silica.

SILT - A very fine-grained sediment, most of the particles of which are between 1/16 and 1/256 millimeters in diameter.

SLIP FACE - The steep, leeward side of a migrating dune.

SLUMP - The downward slipping of a mass of rock or unconsolidated material of any size, moving as a unit or as subsidiary units, usually with backward rotation of a more or less horizontal axis parallel to the cliff or slope from which it descends.

SORTING - (1) In a genetic sense the term may be applied to the dynamic process by which material having some particular characteristic, such as similar size, shape or specific gravity, is selected from a larger heterogeneous mass. (2) In a descriptive sense the term may be used to indicate the degree of similarity, in respect to some particular characteristic, of the component parts in a mass of material.

SORTING COEFFICIENT - A mathematical measure of the degree of sorting of a sediment.

SPIT - A small point of land or a narrow shoal projecting into a body of water from the shore.

SPUR - A short section of sand fence attached to and perpendicular to a longer section that is parallel to the beach.

STEM - The ascending axis of a plant, whether above or below ground, which ordinarily grows in an opposite direction to the root or descending axis.

STILLWATER LEVEL - The elevation that the surface of the water would assume if all wave action were absent.

STRATIFIED - Formed or lying in beds, layers or strata.

STRATIFIED DRIFT - Drift exhibiting both sorting and stratification, implying deposition from a fluid medium such as water or air.

STRATIGRAPHIC - Of, relating to or determined by stratigraphy. The study and correlation of stratified rocks according to origin, composition, distribution and succession of strata.

SURFICIAL GEOLOGY - The study of materials formed on, situated at or occurring on the earth's surface (especially unconsolidated residual, alluvial or glacial deposits lying on the bedrock).

SURF ZONE - The area between the outermost breaker and the limit of wave uprush.

SWASH - The rush of water up onto the beach face following the breaking of a wave.

SWELL - Wind-generated waves that have traveled out of their generating area. A swell characteristically exhibits a more regular and longer period and has flatter crests than waves that are near their area of generation.

TERMINAL MORAINE - A moraine formed across the course of a glacier at its farthest advance, at or near a relatively stationary edge or at places marking the termination of important glacial advances.

TIDAL CURRENT - See CURRENT, TIDAL.

TIDAL, RANGE - The difference in height between consecutive high and low (or higher high and lower low) waters.

TIDE - The periodic rising and falling of the water that results from gravitational attraction of the moon and sun and other astronomical bodies acting upon the rotating earth. Although the accompanying horizontal movement of the water resulting from the same cause is also sometimes called the tide, it is preferable to designate the latter as TIDAL CURRENT, reserving the name TIDE for the vertical movement.

TILL - Nonsorted, nonstratified sediment carried or deposited by a glacier.

TOPOGRAPHY - The configuration of a surface, including its relief, the position of its streams, roads, buildings, etc.

TROPICAL CYCLONE - See HURRICANE.

TROPICAL STORM - A tropical cyclone with maximum winds less than 75 miles per hour.

TURBULENT FLOW - That type of flow in which the stream lines are thoroughly confused through heterogeneous mixing of flow as opposed to laminar flow in which the stream lines remain distinct from one another over their entire body.

UNCONFORMABLY - Not succeeding the underlying strata in immediate order of age and in parallel position.

UNSTRATIFIED - Not formed or deposited in beds or strata.

WASHLINE - See HIGH-WATER MARK.

WASHOVER - Small delta built on the landward side of a bar separating a lagoon from the open sea. A washover results from storm waves breaking over low parts of the bar and depositing sediment on the lagoon side.

WASHOVER CHANNEL - Depression leading across a low dune from the ocean side to the washover on the lagoon side. Formed when a wave breaches a low dune.

WATER TABLE - The upper surface of a zone of saturation, except where that surface is formed by an impenetrable body.

WAVE - A ridge, deformation or undulation of the surface of a liquid.

WAVE AMPLITUDE - See AMPLITUDE, WAVE.

WAVE CREST - See CREST OF WAVE.

WAVE DIRECTION - The direction from which a wave approaches.

WAVE ENERGY FLUX - The rate at which energy is transmitted in the direction of wave propagation across a plane perpendicular to the direction of wave advance and extending down the entire depth.

WAVE FRONT - On a wave refraction diagram, a line drawn parallel to the wave crests or perpendicular to the wave rays. (See Figure 3 located at the end of the glossary.)

WAVE HEIGHT - The vertical distance between a crest and the preceding trough.

WAVELENGTH - The horizontal distance between similar points on two successive waves measured perpendicular to the crest. (See Figure 2.)

WAVE PERIOD - The time for a wave crest to traverse a distance equal to one wavelength. The time for two successive wave crests to pass a fixed point.

WAVE RAY - On a wave-refraction diagram, a line drawn perpendicular to the wave crests. Also ORTHOGONAL. (See Figure 3.)

WAVE RAY-SHORELINE ANGLE - The angle that an incoming wave ray makes with the shoreline.

WAVE REFRACTION - See REFRACTION OF WATER WAVES.

WAVE TROUGH - The lowest part of a wave form between successive crests. Also that part of a wave below stillwater level.

WEATHERED - Altered by a group of processes, such as the chemical action of air and rain water and of plants and bacteria, and the mechanical action of temperature changes, whereby rocks on exposure to the weather change in character, decay and finally crumble into soil.

WIND SETUP - (1) The vertical rise in the stillwater level on the leeward side of a body of water caused by wind stresses on the surface of the water. (2) The difference in stillwater levels on the windward and the leeward sides of a body of water caused by wind stresses on the surface of the water. (3) Synonymous with STORM SURGE. STORM SURGE is usually reserved for use on the ocean and large bodies of water. WIND SETUP is usually reserved for use on reservoirs and smaller bodies of water.

WINDWARD - The direction from which the wind is blowing.

WISCONSIN - Fourth Pleistocene epoch of glaciation.

SOURCES

Definitions in this glossary came from the following sources:

American Geological Institute, 1962. Dictionary of Geological Terms, Dolphin books, Doubleday & Company, Inc., Garden City, New York.

U.S. Army Coastal Engineering Research Center, 1975. Shore Protection Manual. Three Volumes. U.S. Army Coastal Engineering Research Center, Kingman Building, Fort Belvoir, Virginia.

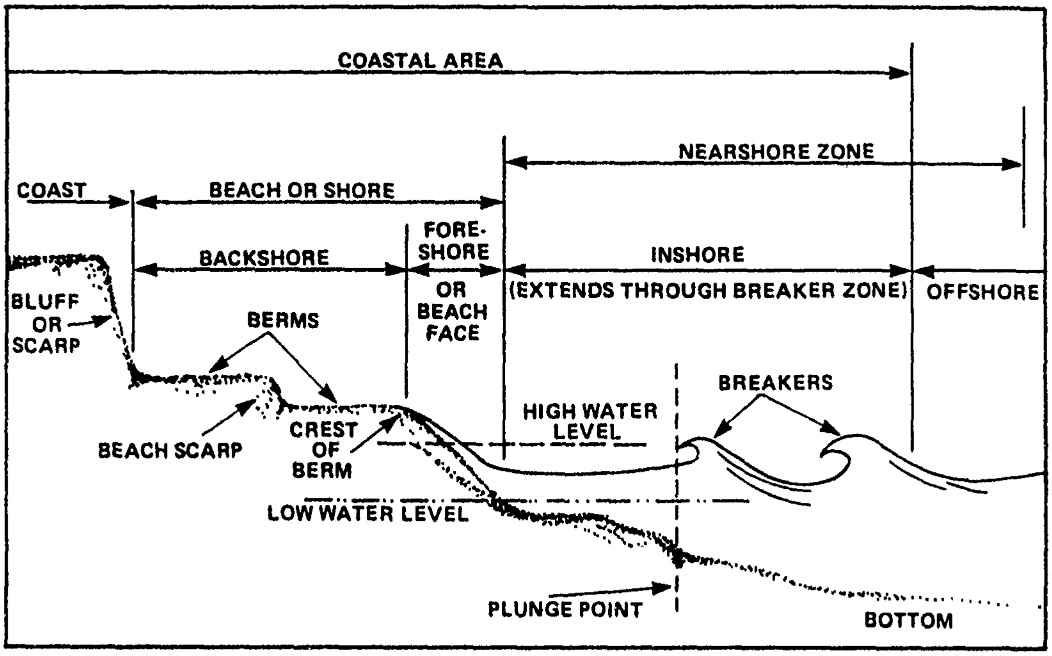


Figure 1. Beach Profile-Related Terms (after U.S. Army Coastal Engineering Research Center, 1975).

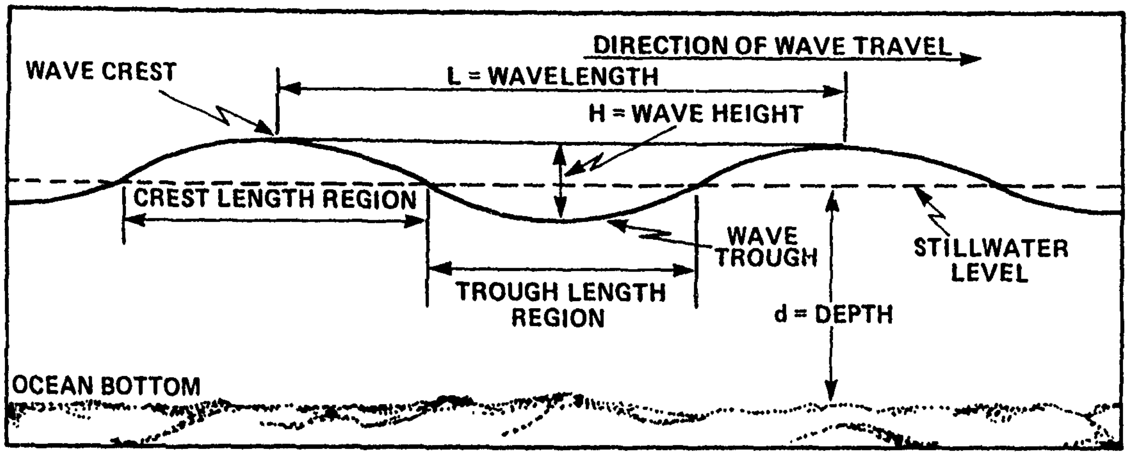


Figure 2. Wave Characteristics and Direction of Water Particle Movement (after Wiegel, 1953).

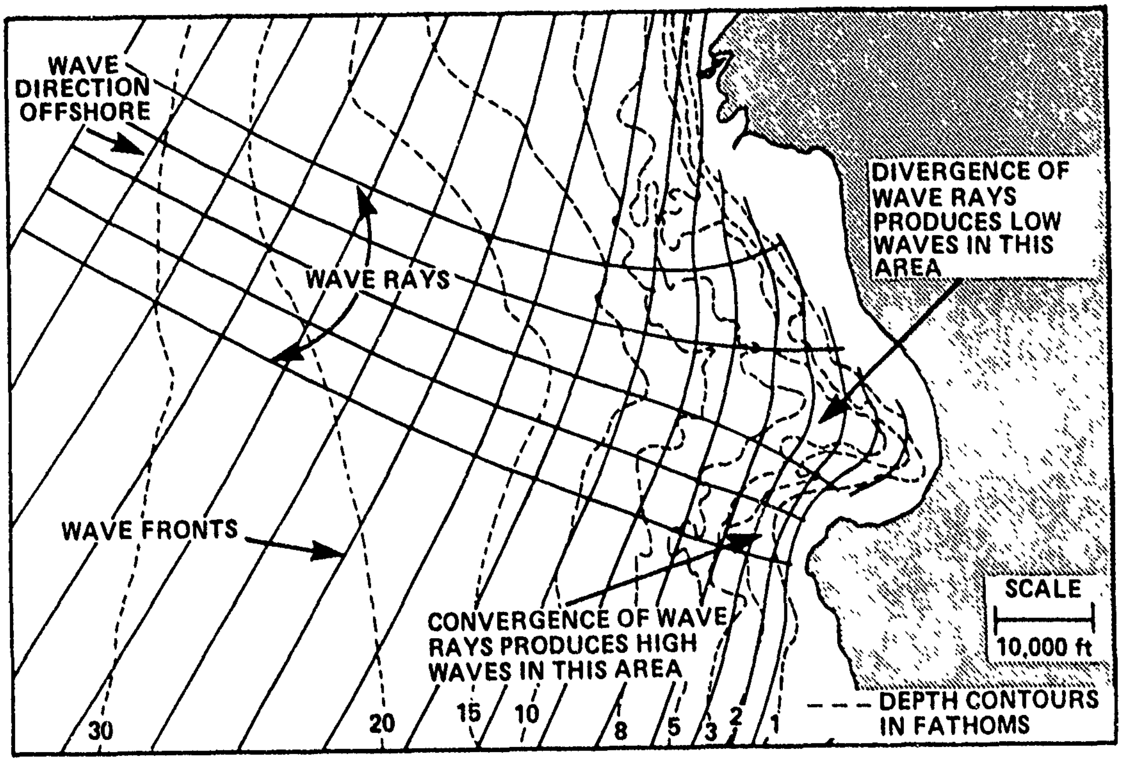


Figure 3. Refraction Diagram (after Wiegel, 1953)